Spin Physics at STAR

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BNL

For STAR Collaboration

Contents:

- Short introduction nucleon spin structure
- STAR spin physics program
  - Some example of physics cases
- STAR detector
- High lights of physics from last run data
- Plans for next and future runs
- Summary

The spin of the nucleon

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

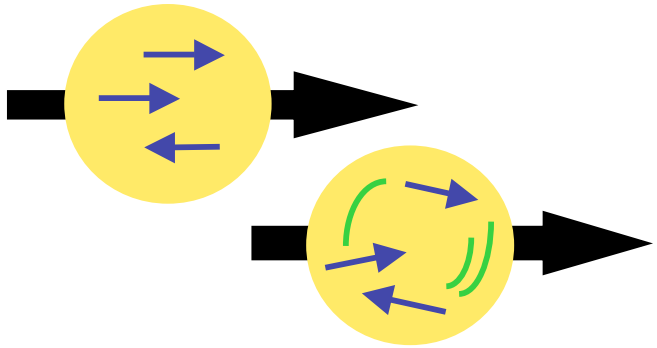
Quark spin Gluon Spin Angular momentum

Non-relativistic Quark Model $\Delta\Sigma=1$

Relativity reduce to $\Delta\Sigma\approx 0.7$

Ellis Jaffe Sum rule $\Delta\Sigma\approx 0.6$

SU(3) and non polarized sea quark

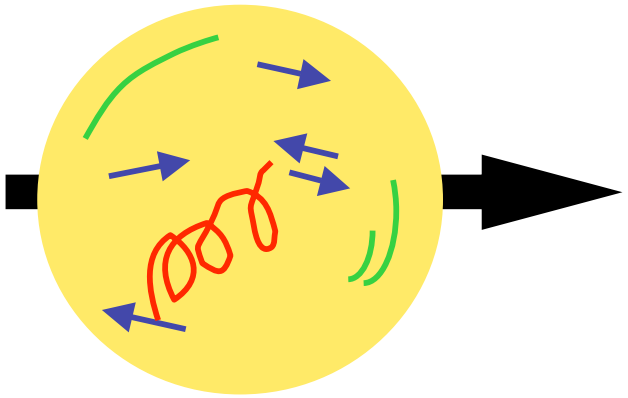


Measurement from polarized DIS

$\Delta\Sigma\approx 0.2$

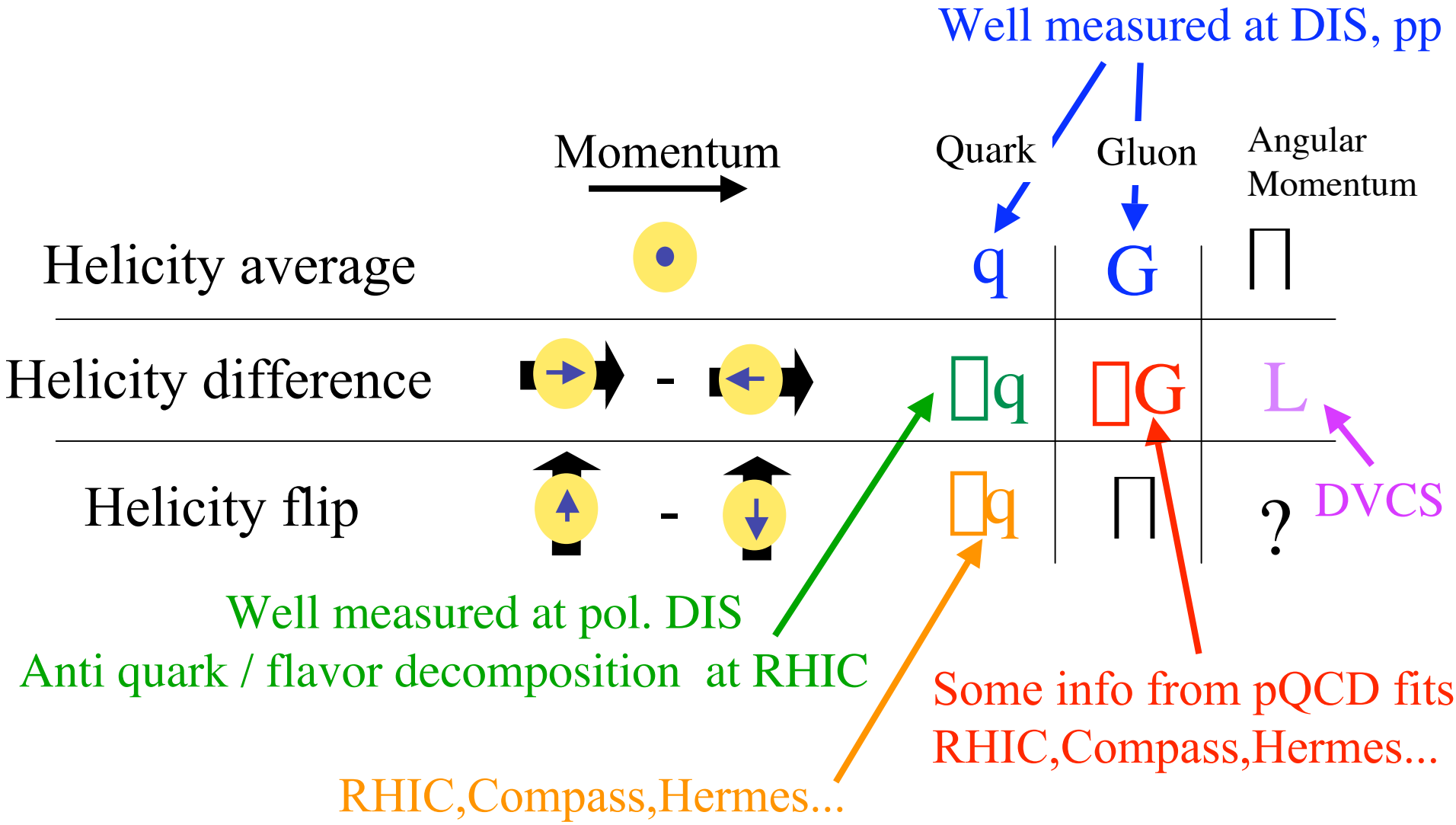
Pion cloud model

Massless QCD conserve helicity



→ Cannot generate gluon & sea quark polarization

Leading twist parton distributions



Spin Physics Program at STAR

Gluon Polarization

Direct Photon + jet $qg \rightarrow q\gamma$ QCD Compton scattering

Jet and di-Jet $qg \rightarrow Jet + Jet$ or $gg \rightarrow Jet + Jet$

Heavy flavor production (?)

Quark / Anti-Quark Polarization & Flavor Decomposition

W production $q\bar{q} \rightarrow W^{\pm} \rightarrow e^{\pm}$

Transversity & Transverse Spin Effects

Transversity via Jet fragmentation

Transversity via Dijet or Drell-Yan

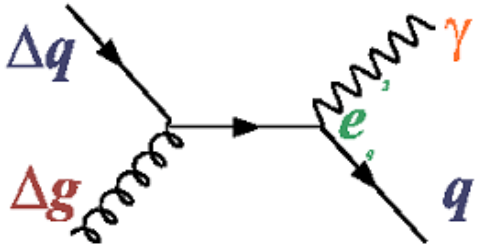
Single transverse spin asymmetries

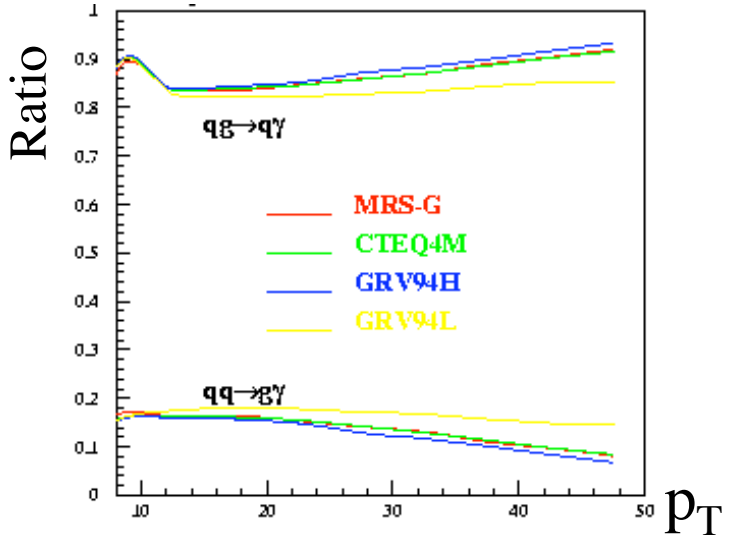
New Physics?

Parity violating asymmetries

Gold plated channel for ΔG: γ+Jet

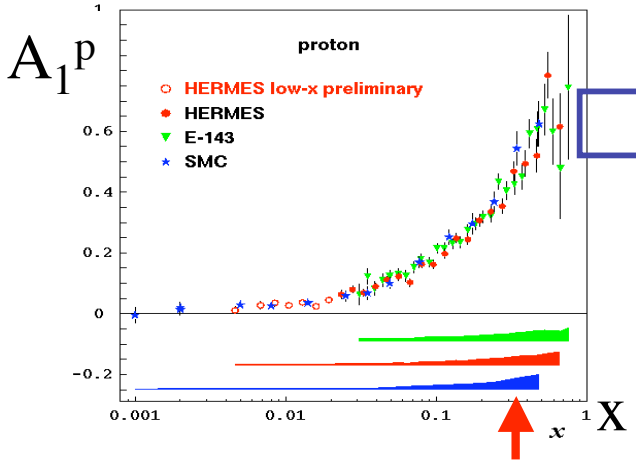
~90% is from QCD Compton



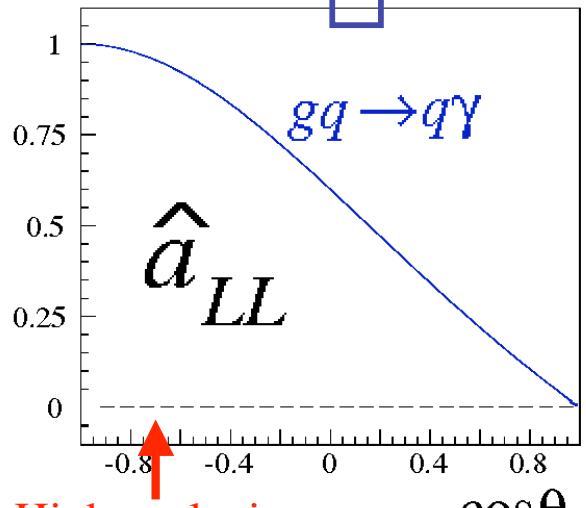


$$A_{LL} \approx \frac{\Delta g(x_1)}{g(x_1)} \frac{\sum_i e_i^2 \Delta q_i(x_2)}{\sum_i e_i^2 q_i(x_2)} \hat{a}_{LL}(gq \to q\gamma)$$

From QCD



Exactly equal to A_1^p
as measured at pol. DIS
No Fragmentation function



High x quark with high polarization

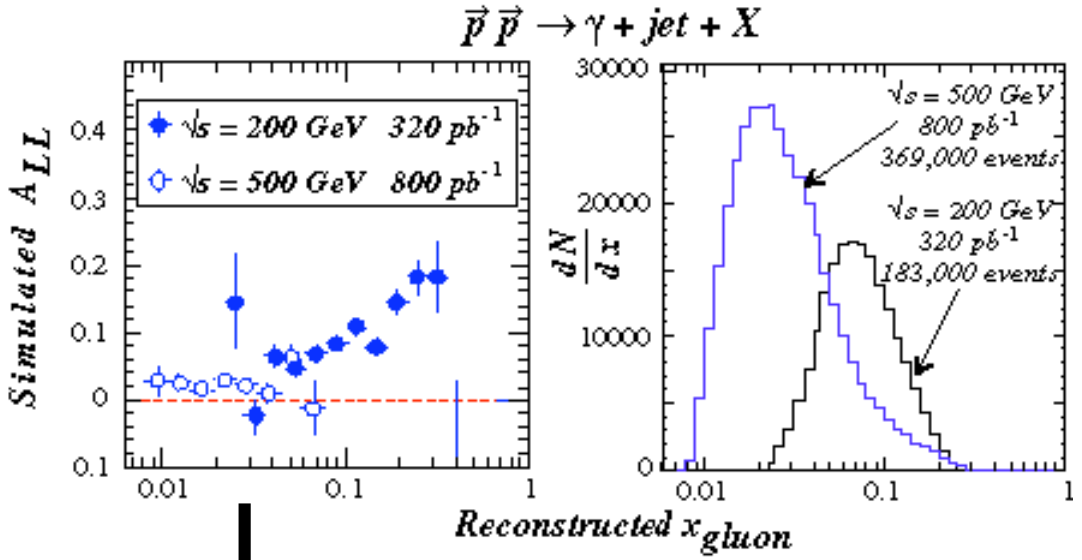
Go forward direction
Endcap EMC

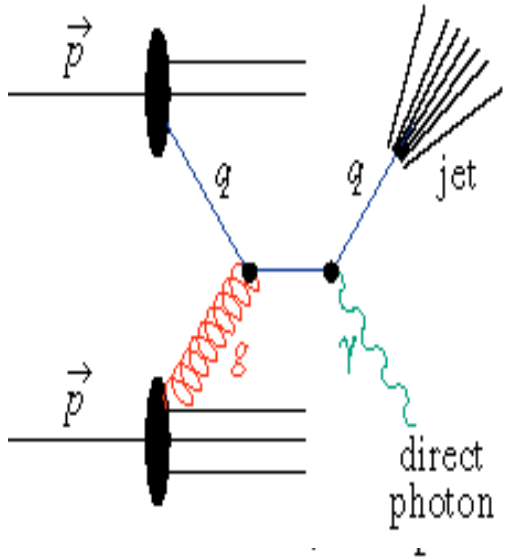
High analyzing power
with backscattering

STAR Sensitivity to ΔG

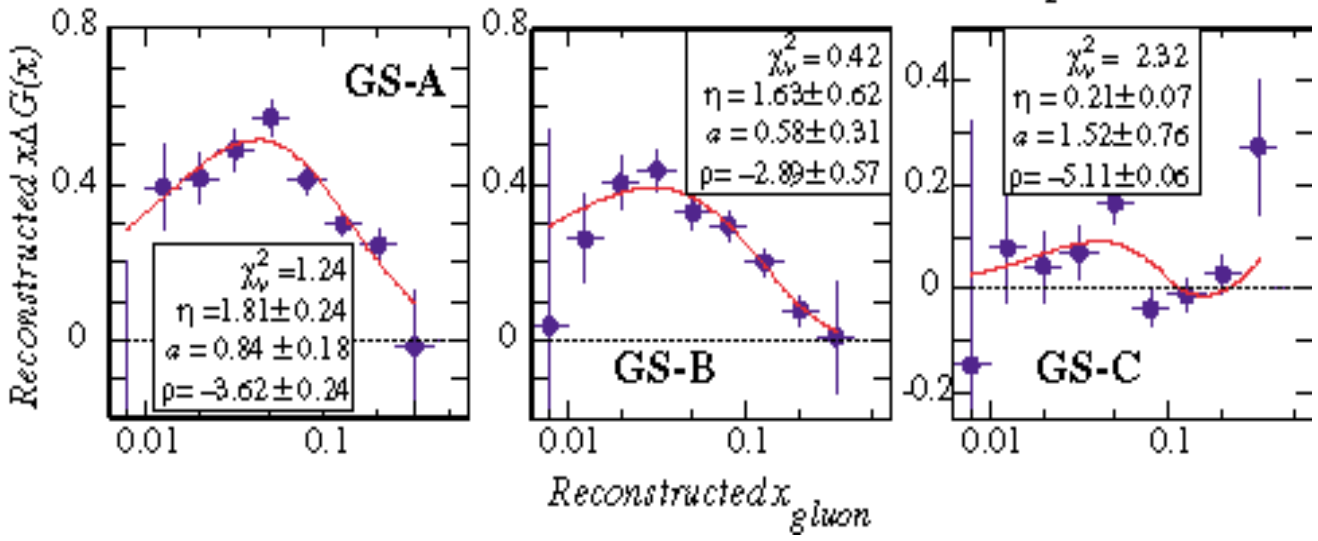
STAR's wide acceptance = Coincident detection of π and away-side jet direction

→ Determination of initial-state partonic kinematics.

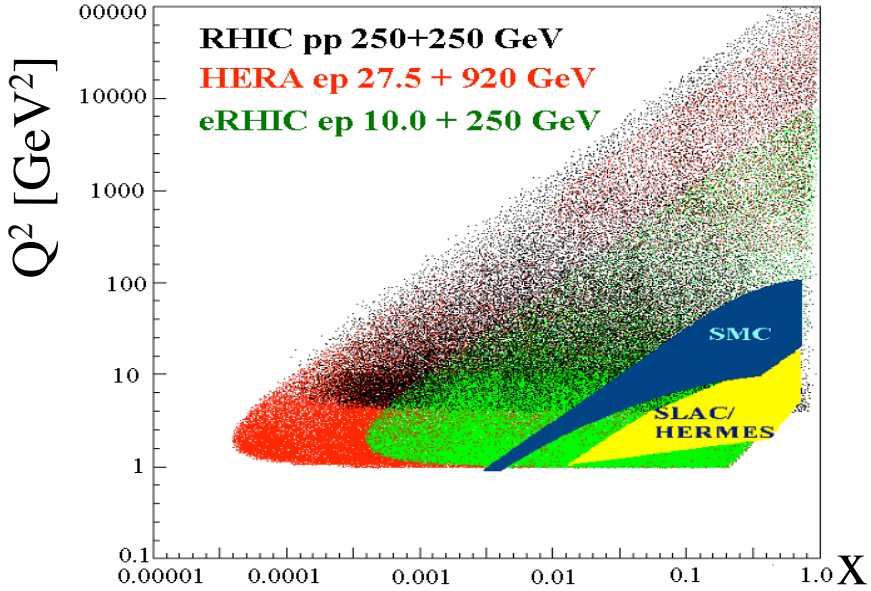


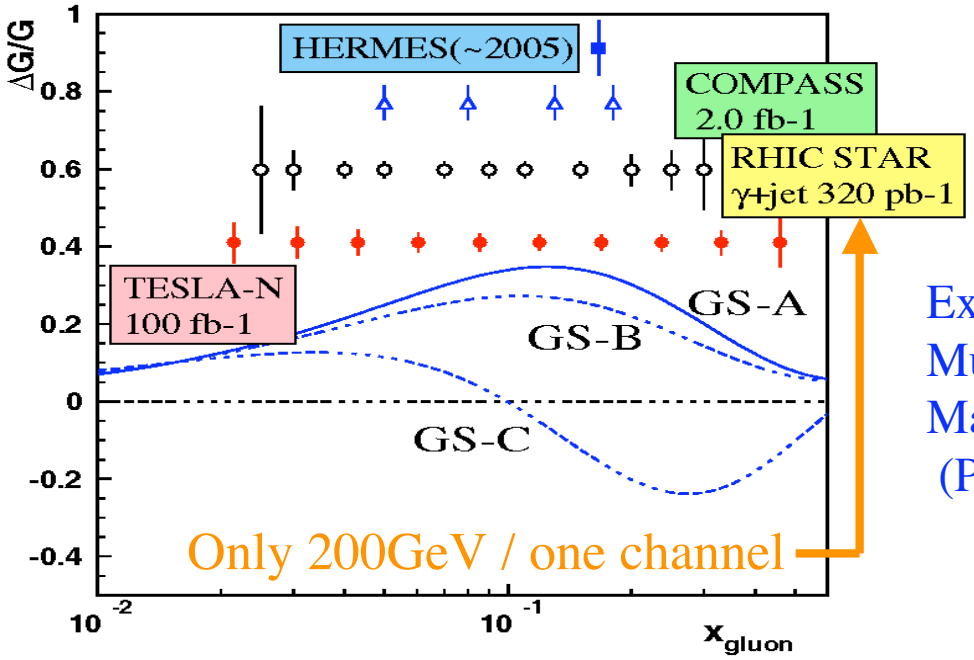


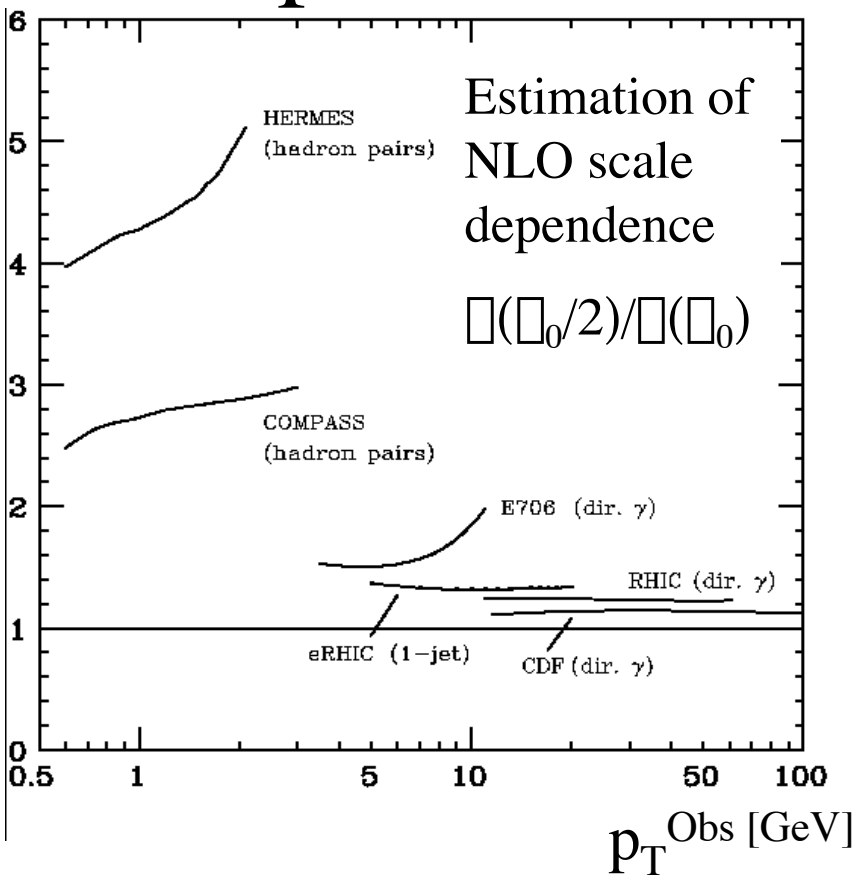
200 and 500GeV
Going to forward rapidity
Better sensitivity
Wider x range
to determine integral



Comparison with other experiments





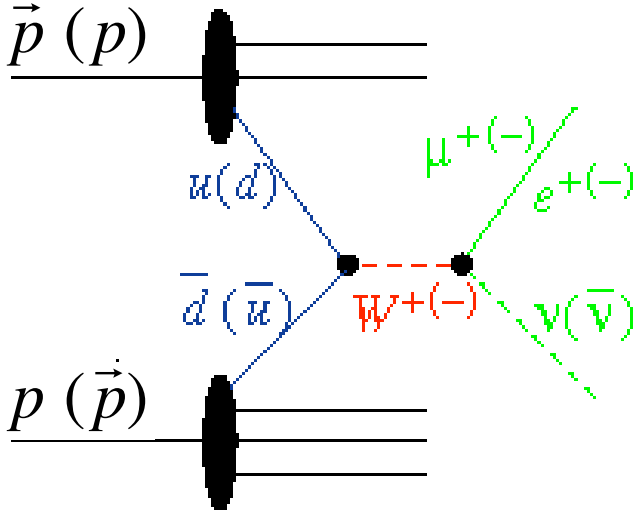


Extends kinematics to high Q^2 and low x
Much smaller scale dependence
Many different channels
(Photon, jets, heavy flavor production)

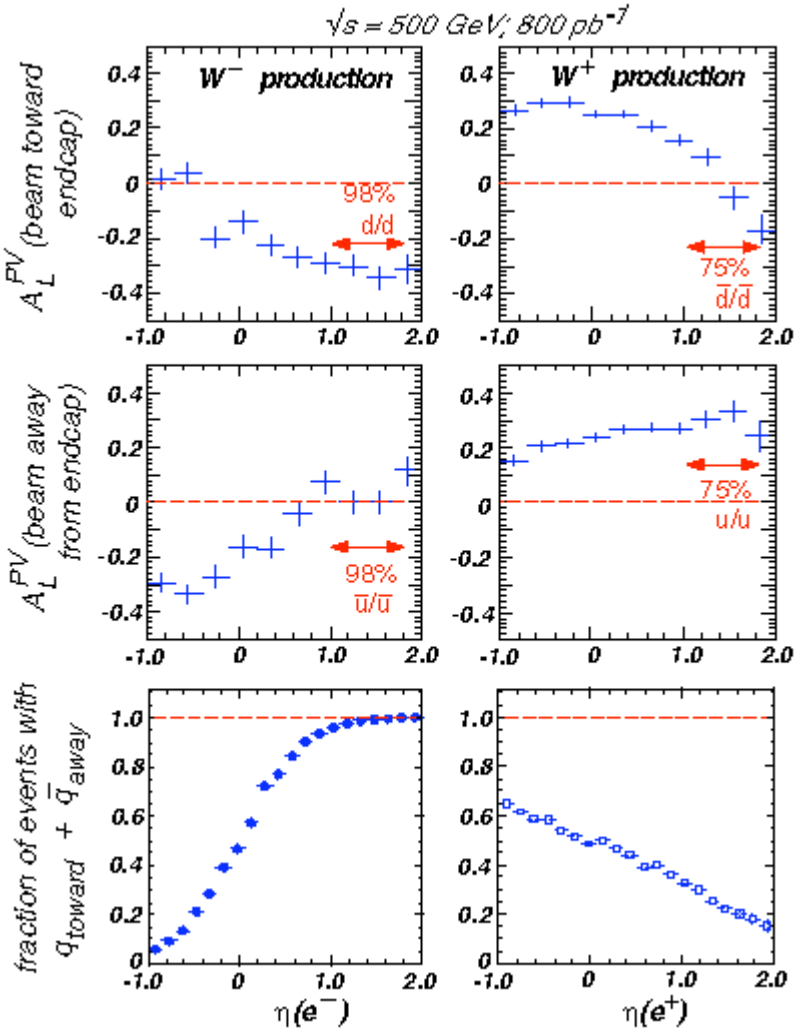
→ Determine integral of ΔG
Global QCD fit analysis

Flavor Decomposition of the proton's spin

W select spin and flavor



$$\vec{p} + p \rightarrow \vec{W}^{\pm} \rightarrow e^{\pm}$$



Forward (backward) lepton measurement

$$A_L^{e^+}(\vec{p}p) \rightarrow \bar{d}/\bar{d}$$

$$A_L^{e^+}(p\vec{p}) \rightarrow u/u$$

$$A_L^{e^-}(\vec{p}p) \rightarrow \bar{u}/\bar{u}$$

$$A_L^{e^-}(p\vec{p}) \rightarrow d/d$$

Blue beam toward endcap

Yellow beam away from endcap

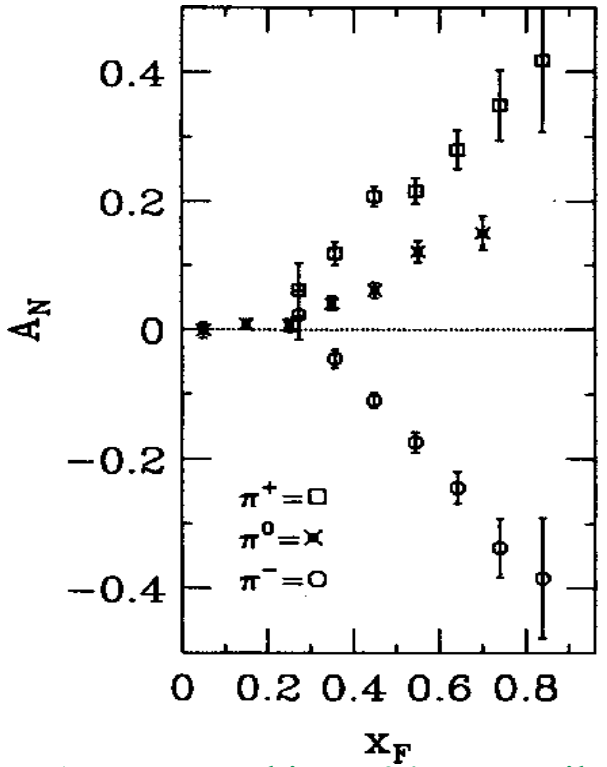
Transverse Spin Physics

E704 A_N "Mystery"
Transversity * "Collins-Heppelmann Fragmentation Function"?
"Sivers Effect" or "Intrinsic handedness" ? (Anglar Momentum?)
Twist-3 gluon correlations?

Forward rapidity high x_F pi0 A_N
Mid rapidity charged particle A_N
Forward rapidity charged particle A_N

↳ Exciting results are reported at this conference

Transversity measurements



Non-zero A_N measured in E704 at Fermilab at sqrt(s)=20 GeV, p_T=0.5-2.0 GeV/c:

"Complete" Transversity Measurements

Polarized pp - RHIC Star/Phenix (BNL)

Drell Yan or di-Jets: $A_{TT}(p_\uparrow p_\uparrow \to ll/jet+jet) \propto \delta q \cdot \delta q$

Collins Effect : $A_T\left(p_\uparrow + p \to jet(h) + X\right) \propto \delta q \cdot C$

$\pi^+\pi^-$ Interference Fragmentation : $A_T\left(p_\uparrow + p \to jet(\pi^+,\pi^-) + X\right) \propto \delta q \cdot \delta\hat{q}_I$

Inclusive hadron: $A_N(p_\uparrow p \to h) \propto \delta q \cdot C + \text{other terms}$

Polarized DIS - Hermes(DESY) Compass(CERN) eRHIC Tesla-N

Collins Effect : $A_T(lp_\uparrow \to l+\pi+X) \propto \delta q \cdot C$

$\pi^+\pi^-$ Interference Fragmentation : $A_T\left(lp_\uparrow \to jet(\pi^+,\pi^-) + X\right) \propto \delta q \cdot \delta\hat{q}_I$

e+e- collider - Belle (KEK) Babar LEP …

$e^+e^- \to dijet$: $C \cdot C$, $\delta\hat{q}_I \cdot \delta\hat{q}_I$ & $C \cdot \delta\hat{q}_I$ → K. Hasuko's talk on Friday

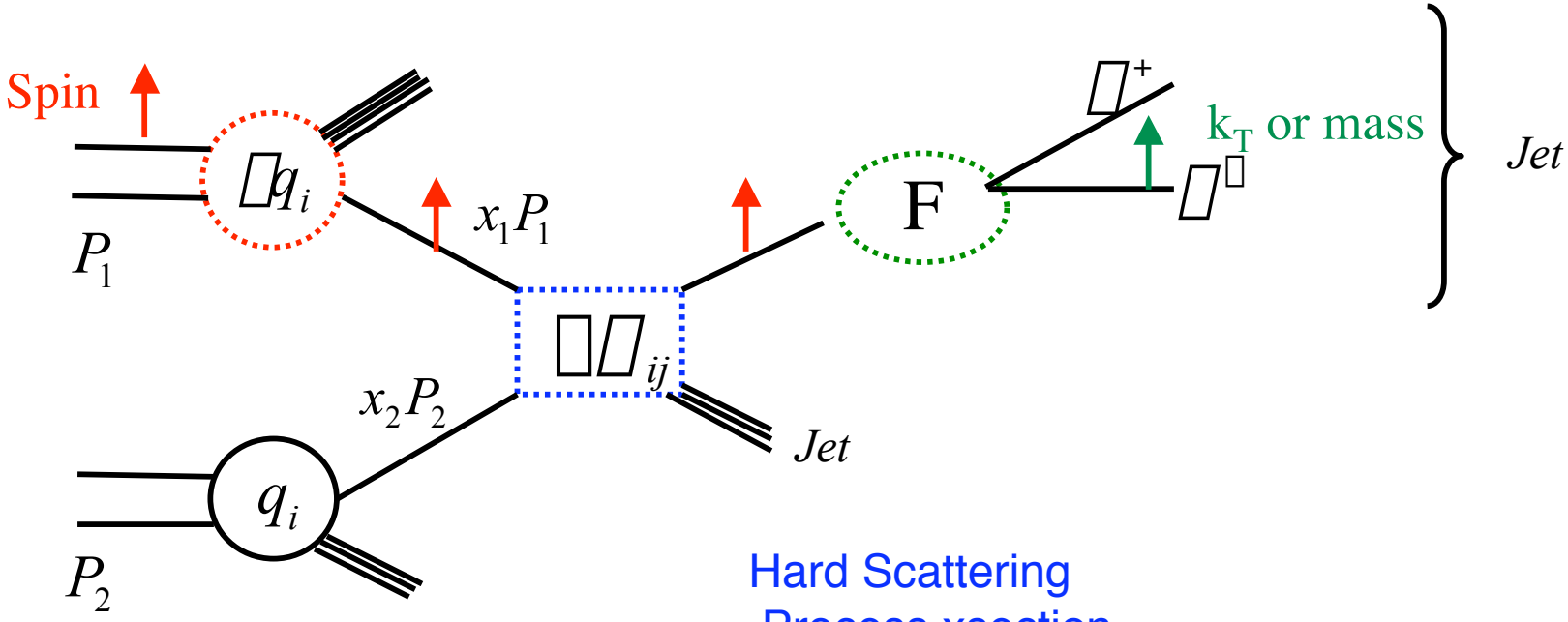
Tensor Charge Lattice calculations - RBRC ….

$\delta T = \delta u + \delta d + \delta s = 0.56 \pm 0.09$

S. Aoki, M. Doui, T. Hatsuda and Y. Kuramashi Phys.Rev. D56 (1997)433
More recently: S. Capitani et.al. Nucl. Phys. B (Proc. Suppl.) 79 (1999) 548

Transversity at STAR

using spin dependent jet Fragmentation Function(FF)



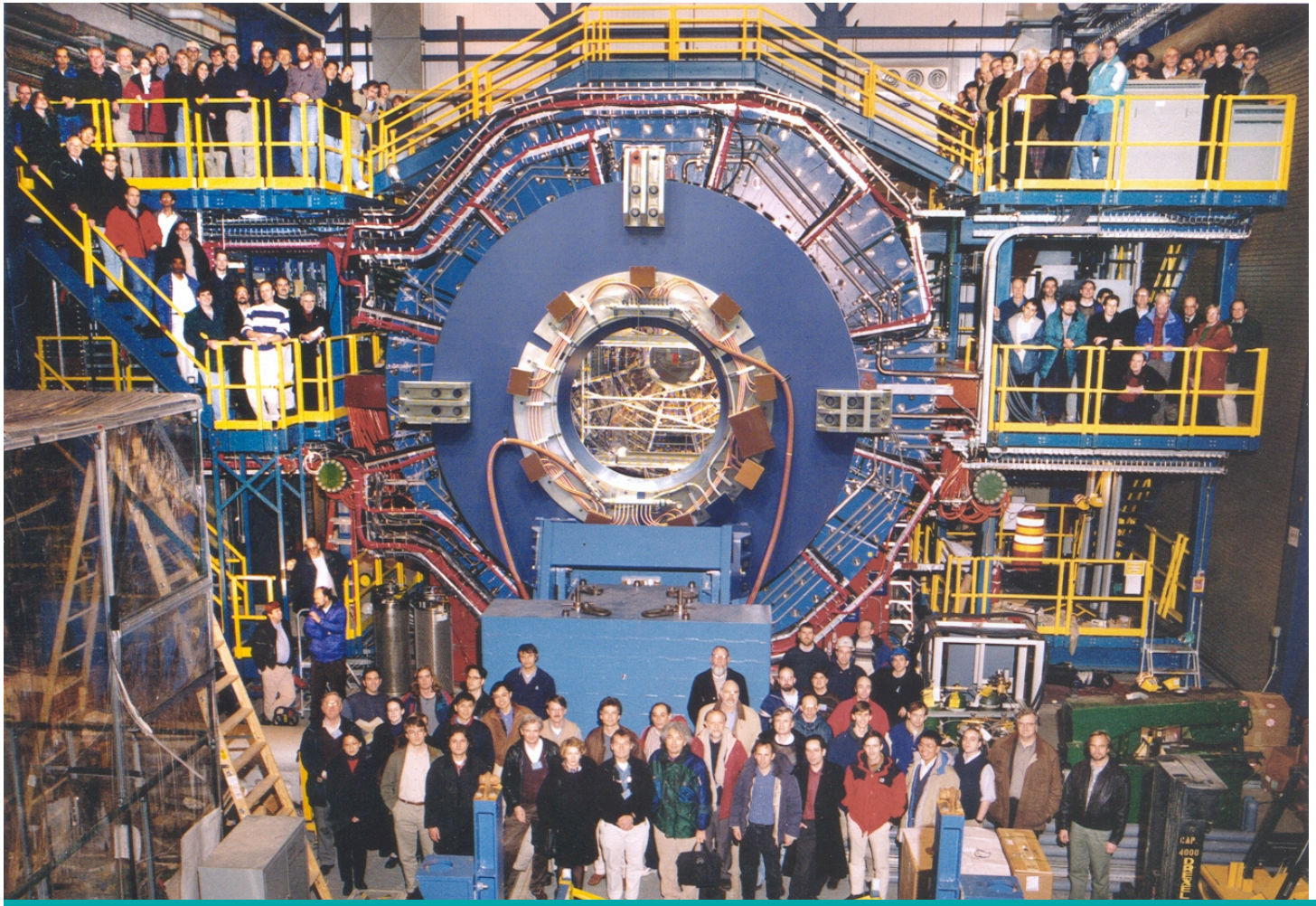
$$\frac{d^6\Delta_H\left(pp^{\uparrow}\ \square\ \square^{+}\square^{-}X\right)}{dx_1dx_2dtdzdm^2d\square} \quad \square q(x_1)\cdot q(x_2) \quad \frac{d^3\square(q_1q_2\ \square\ q_3q_4)}{dx_1dx_2dt} \quad \frac{d^3F}{dzdm^2d\square}$$

Hard Scattering Process xsection

Transversity

Collins- Heppelmann FF
or
2 pion Interference FF

Requires to measure Jets
stay away from initial state effects
FF depends on z



STAR spin

The STAR Collaboration

~ 400 collaborators
41 institutions
9 countries

Brazil: Sao Paolo

England: Birmingham

Germany: Frankfurt, MPI - Munich

India: Bhubaneswar,Jammu,IIT-Mumbai, Panjab, Rajasthan, Kolkata

France: IReS - Strasbourg, SUBATECH-Nantes

Poland: Warsaw University, Warsaw U. of Technology

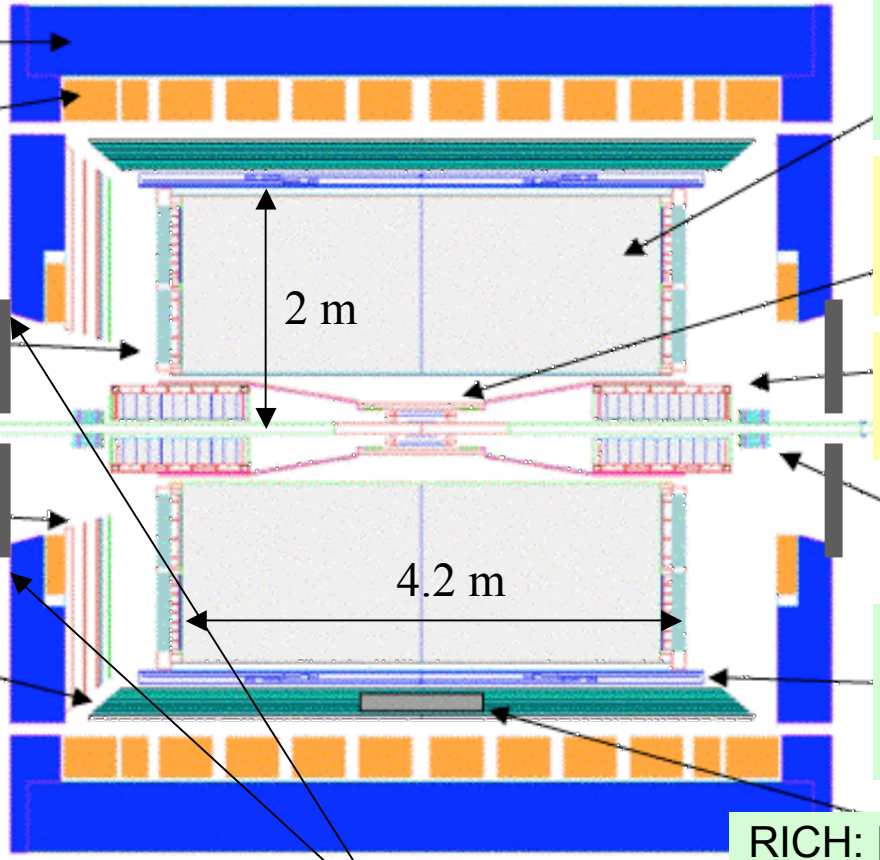
Russia: MEPHI - Moscow, JINR - Dubna, IHEP – Protvino

China: IHEP - Beijing, IPP – Wuhan, Lanzhou, USTC, SINR,Tsinghua

U.S.: Argonne, Lawrence Berkeley, Brookhaven National Laboratories
UC Berkeley, UC Davis, UCLA, Creighton, Carnegie-Mellon, Indiana, Kent State, MSU, CCNY, Ohio State, Penn State, Purdue, Rice, Texas, Texas A&M, Washington, Wayne, Yale Universities

STAR – Solenoid Tracker At RHIC

Spin	2001 Year0	2002 Year1	2003- Year2 and beyond



Magnet Coils

B=0.25T | 0.5T

TPC Endcap & MWPC

ZDC

Endcap EMC
1< □ <2 □□ = 2□

Barrel EMC
0< □< 1 □□ =2□/5

|□| < 1 □□ = 2□

Time Projection Chamber |□|< 1.5

Silicon Vertex Tracker

Forward TPCs
2.4 <|□| < 4.0

Vertex Position Detectors

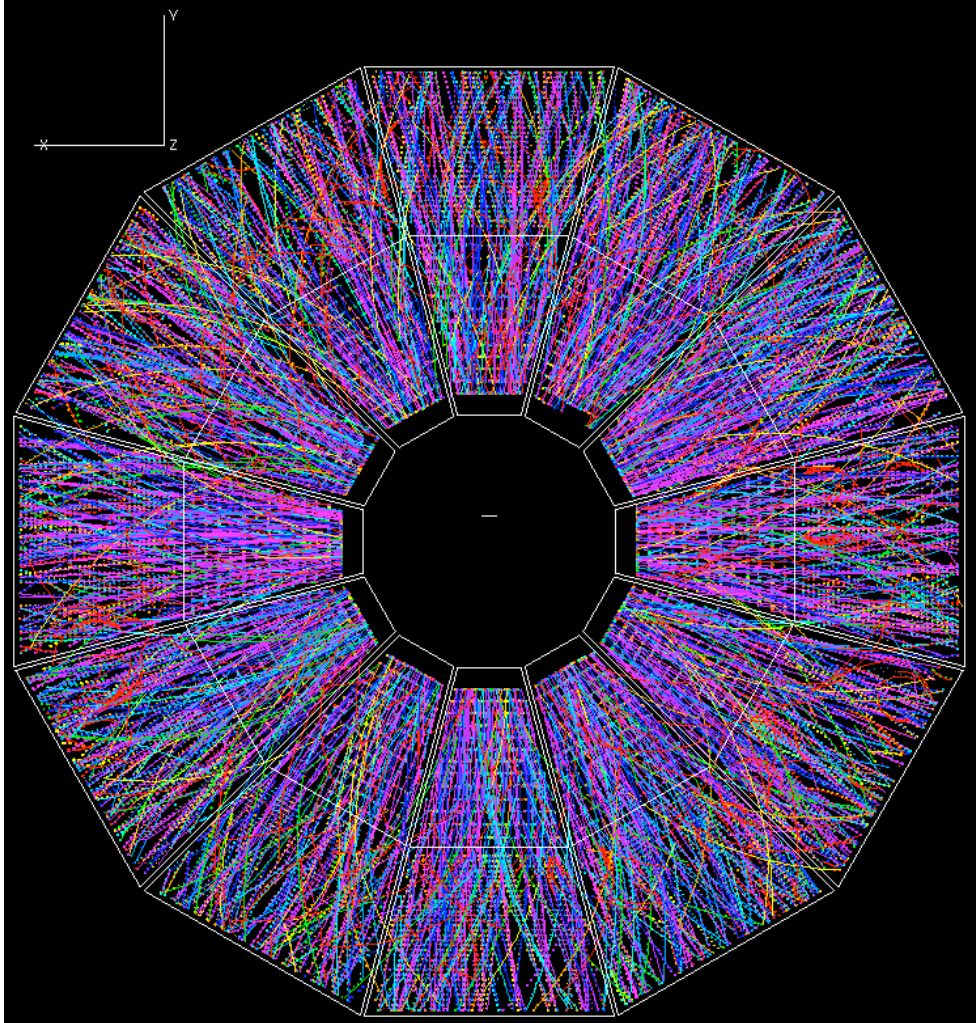
Central Trigger Barrel |□| < 1
+ TOF patch

RICH: |□|<0.3, □□ = □/6

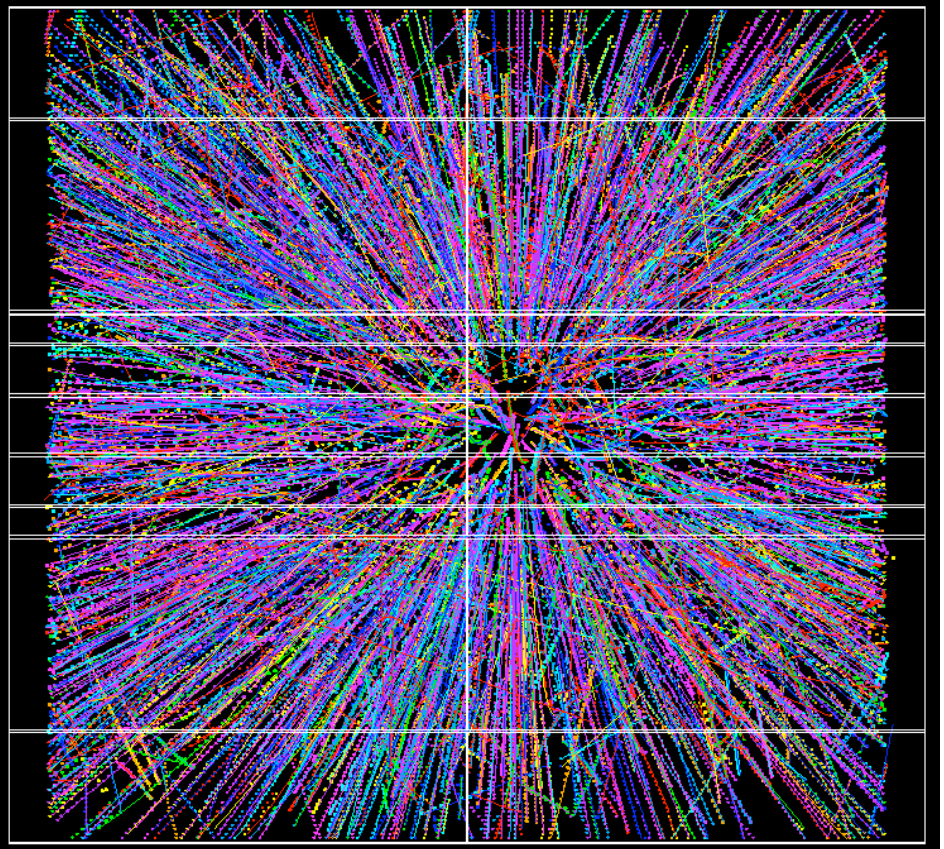
Forward Pion Detector (FPD) 3.0 < □ < 4.0
+ upgrade

Beam-Beam Counters
2.1< |□| < 5.0
+ upgrade

Central Au+Au Collision at s_{NN}=130 GeV



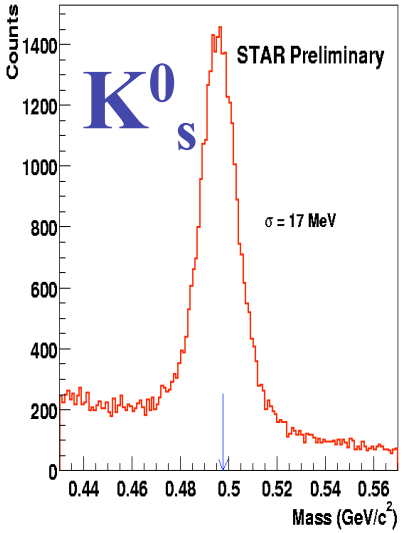
colors ~ ionization: low - - - high

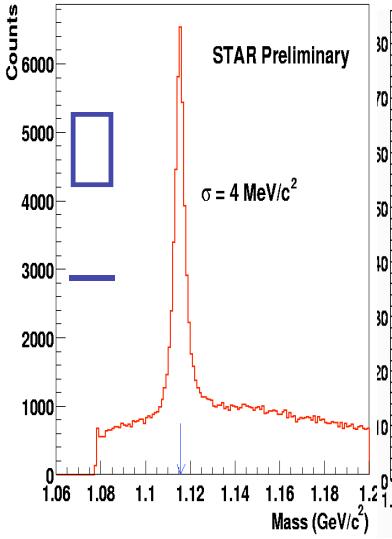


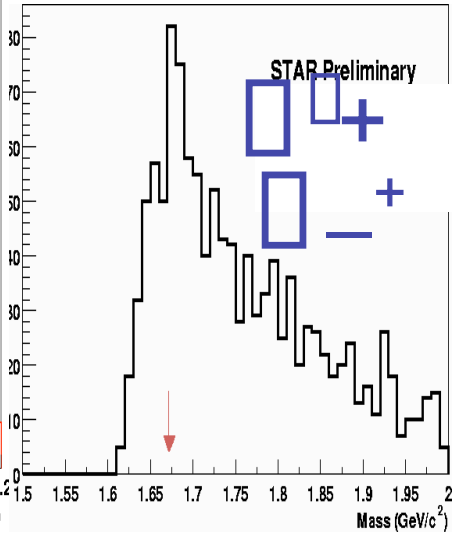
Reconstructed Mass

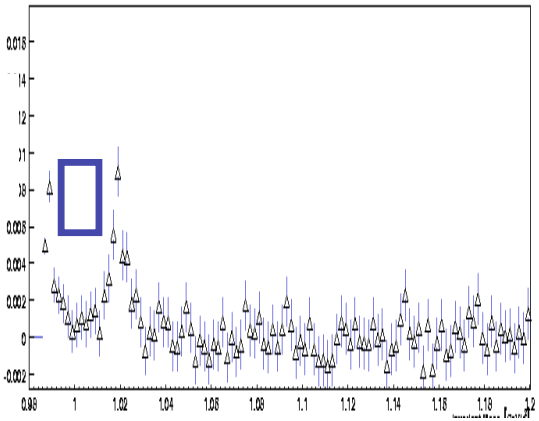
$\mathrm{Au + Au}\ (2000)\ \text{at}\ \sqrt{s_{NN}} = 130\ \mathrm{GeV}$

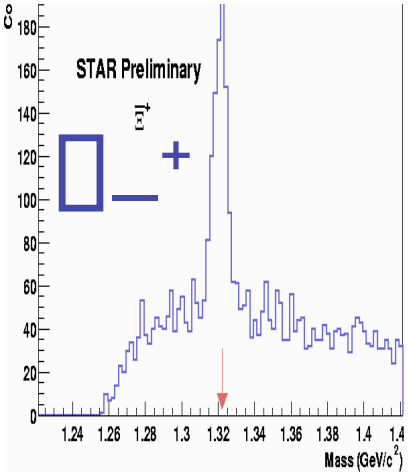
STAR (TPC)

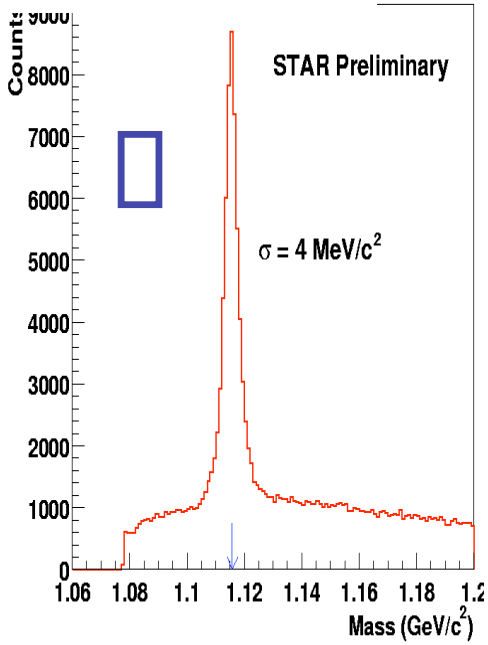


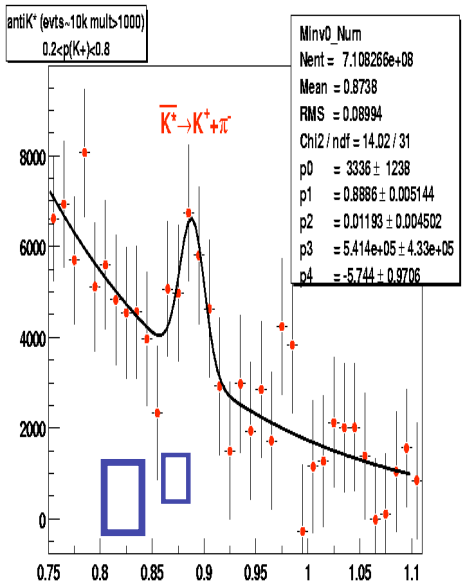


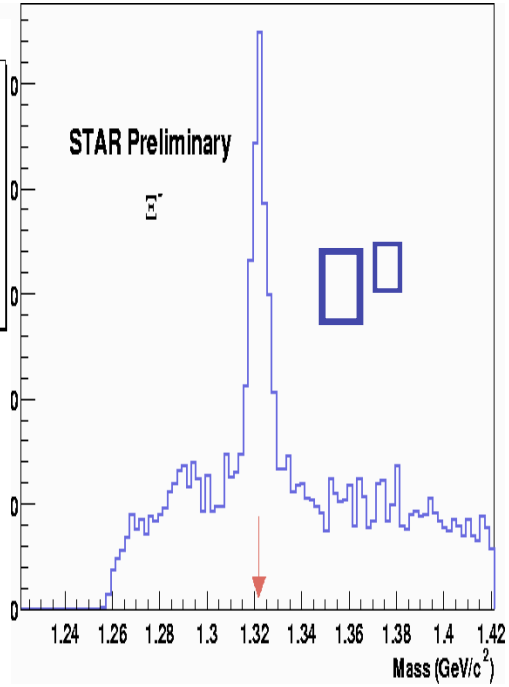












H. Caines, QM2001

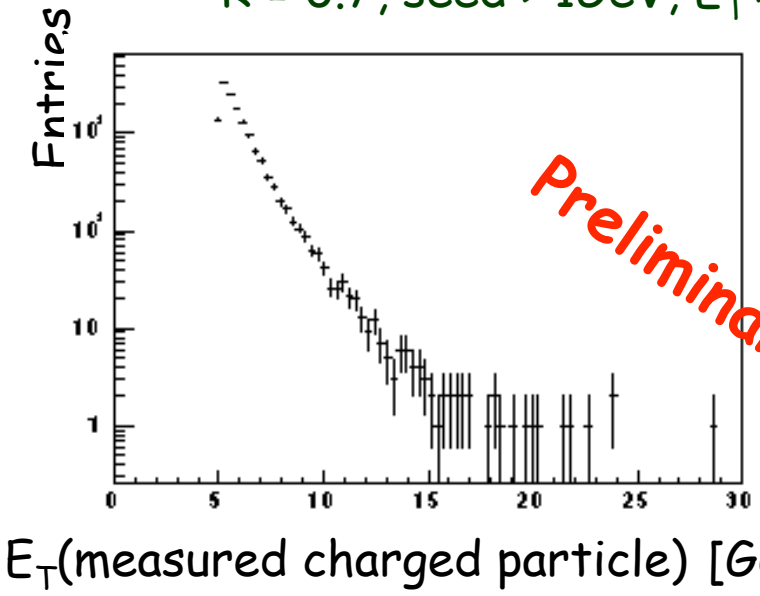
TPC is our hadron calorimeter

- Very first "look" at jets:

  DATA: STAR minimum-bias pp data: $\sqrt{s}$ = 200 GeV

  Jet algorithm: Cone jet Finder for charged particles only

  R = 0.7, seed > 1GeV, E_T > 5GeV, $|\eta^{jet}| < 0.7$

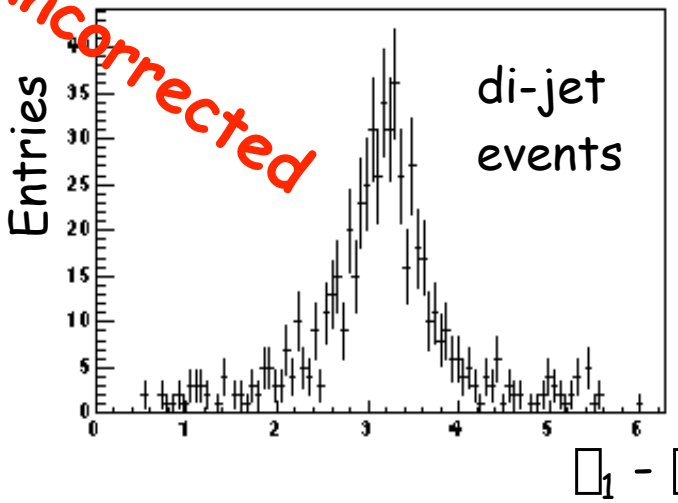


Preliminary uncorrected

Require understanding of detector to set the energy scale

EMC will be added

Physics with jets will be coming



Spin asymmetries in proton-proton collider

Requires 3 different process/measurements

N = spin dependent yields of process interest

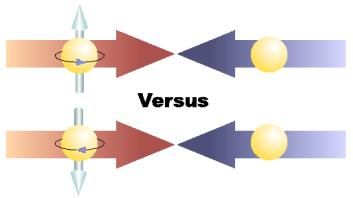
L = yield of luminosity monitoring process (high rate & spin independent)

(R = relative luminosity between different spin configuration)

P = beam polarization(s) from polarimeter at RHIC

Single Spin Asymmetries F.o.M = P^2L

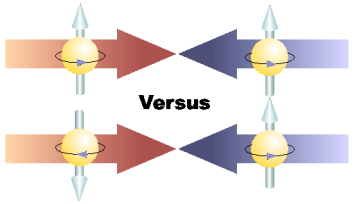
$$A = \frac{1}{P}\left(\frac{N^{\uparrow}/\mathcal{L}^{\uparrow} - N^{\downarrow}/\mathcal{L}^{\downarrow}}{N^{\uparrow}/\mathcal{L}^{\uparrow} + N^{\downarrow}/\mathcal{L}^{\downarrow}}\right) = \frac{1}{P}\left(\frac{N^{\uparrow} - RN^{\downarrow}}{N^{\uparrow} + RN^{\downarrow}}\right) \qquad R = \frac{\mathcal{L}^{\uparrow}}{\mathcal{L}^{\downarrow}}$$



$$= \frac{1}{P}\left[\frac{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} - \sqrt{N_R^{\uparrow} \cdot N_L^{\downarrow}}}{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} + \sqrt{N_R^{\uparrow} \cdot N_L^{\downarrow}}}\right]$$ A_N with left-right symmetric detectors

Double Spin Asymmetries F.o.M = P^4L

$$A = \frac{1}{P_1P_2}\frac{(N^{\downarrow\uparrow}/L^{\downarrow\uparrow} + N^{\uparrow\downarrow}/L^{\uparrow\downarrow}) - (N^{\uparrow\uparrow}/L^{\uparrow\uparrow} + N^{\downarrow\downarrow}/L^{\downarrow\downarrow})}{(N^{\downarrow\uparrow}/L^{\downarrow\uparrow} + N^{\uparrow\downarrow}/L^{\uparrow\downarrow}) + (N^{\uparrow\uparrow}/L^{\uparrow\uparrow} + N^{\downarrow\downarrow}/L^{\downarrow\downarrow})}$$



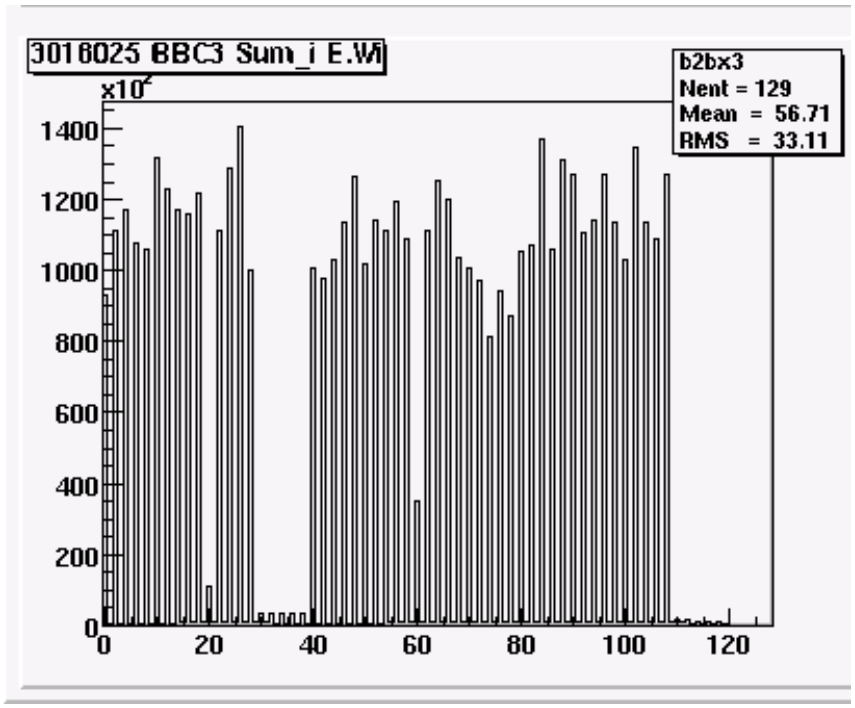
$$= \frac{1}{P_1P_2}\left(\frac{N^{\downarrow\uparrow} - RN^{\uparrow\uparrow}}{N^{\downarrow\uparrow} + RN^{\uparrow\uparrow}}\right) \qquad R = \frac{L^{\downarrow\uparrow}}{L^{\uparrow\uparrow}}$$

We need to measure R in collider environment → J.Kiryluk's Talk

Scaler Board System

24 input bits = 7(bunch crossing) + 17(physics inputs)

Counts input pattern every bunch crossing (every 107nsec)

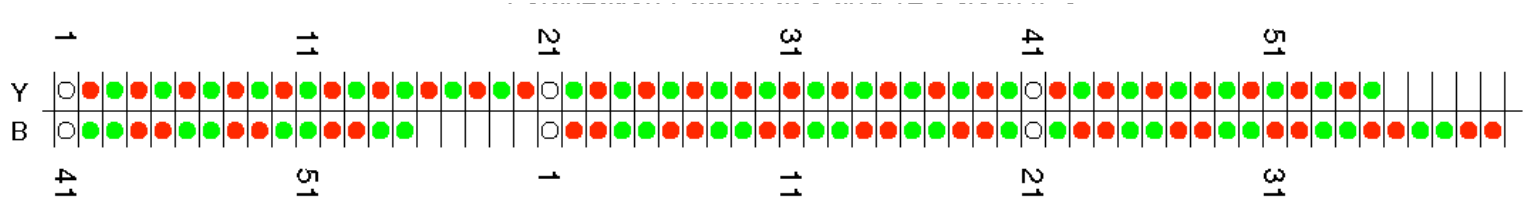


- Study bunch to bunch beam differences
  - Systematic study
  - Feed back to RHIC
- Measure relative luminosity
  - per bunch
  - for many difference processes

    2^{17}=130K different input patterns

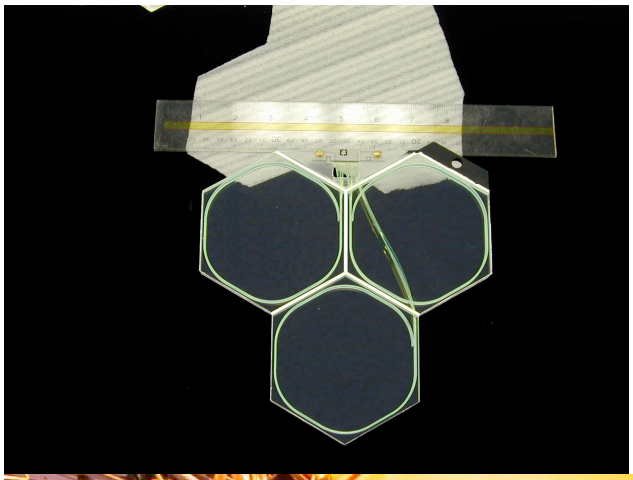
    Essential for next year A_{LL} to check spin (in) dependence in luminosity monitoring process
- Counting spin experiments

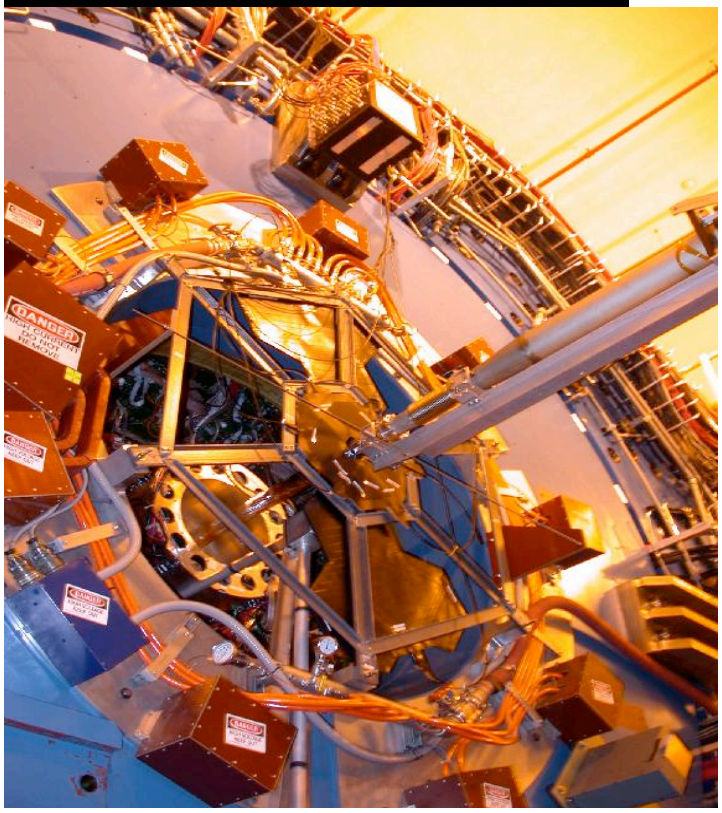
Polarization Pattern at STAR: Spin Up Spin Down Unpolarized



Next run: 10 scaler boards

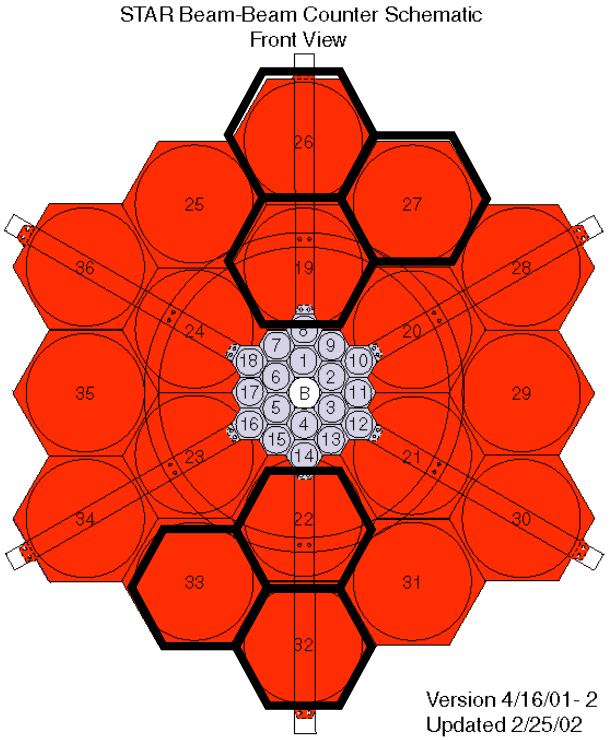
Beam Beam Counter





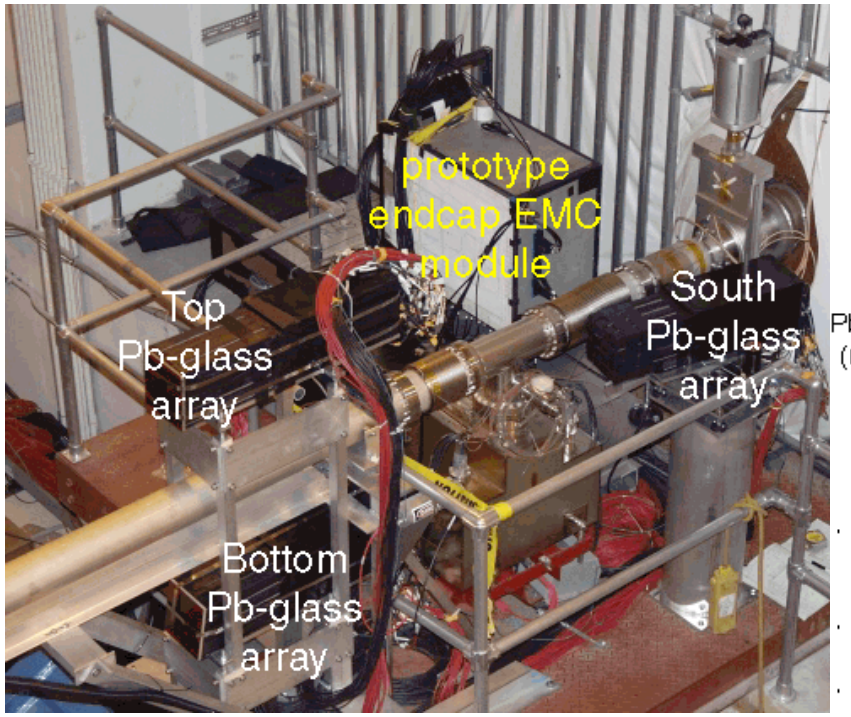
1cm thick scintillator hex tiles with PMT readout (2.1<|□|<5)

1. Feed back to RHIC to make collision at STAR
2. Measure relative luminosity ~10^{-3} level
3. Measure absolute luminosity ~ 15% level
4. Minimum bias trigger (covers ~40% of total □)
5. Reject beam gas events from biased trigger
6. Measure multiplicity at forward rapidity
7. A_N for forward charged particles

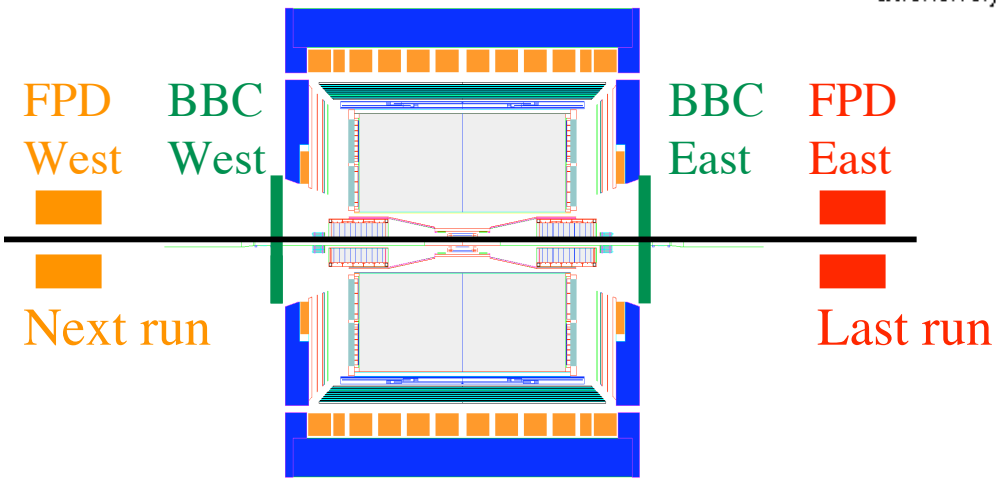


For next run:
Complete large tiles
More PMTs
Better triggering

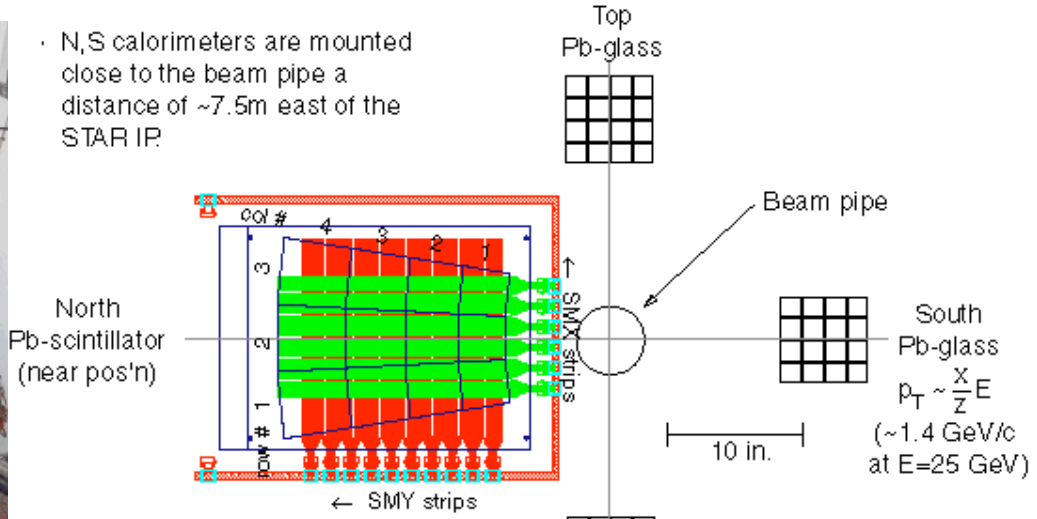
STAR Forward π^0 Detector



Mid rapidity detectors



- N,S calorimeters are mounted close to the beam pipe a distance of ~7.5m east of the STAR IP.
- 12-tower prototype of endcap EMC sampling calorimeter
- preshower detectors
- shower-maximum detector to measure transverse profile
- extensively tested at SLAC



- Pb-glass detectors built by IHEP, Protvino for FNAL E-704
- ~18 radiation lengths
- Cerenkov detector

π^0 reconstruction x_F>0.2~0.6

$1 < p_T < 4$ GeV

$3 < \eta < 4$

For next run: More symmetry

left+right Pb-g + SMD + PreShower

both east & west

Barrel EMC

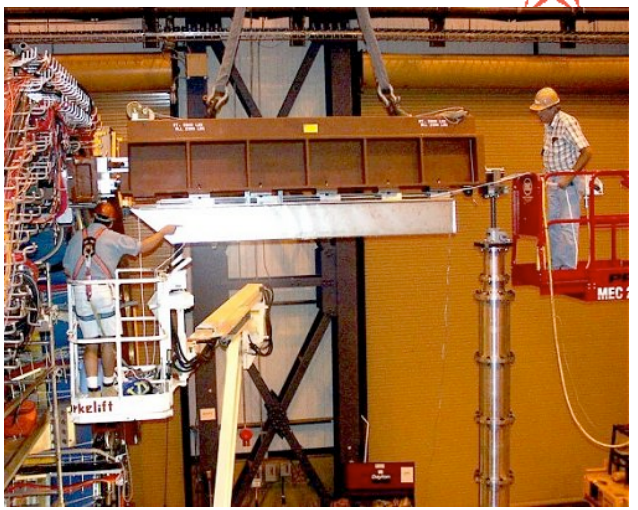
Scinti. + Pb sandwich EMC

4800 projective towers (2□, -1<□ <1)

Shower Max Detector gas detector with 18K strips

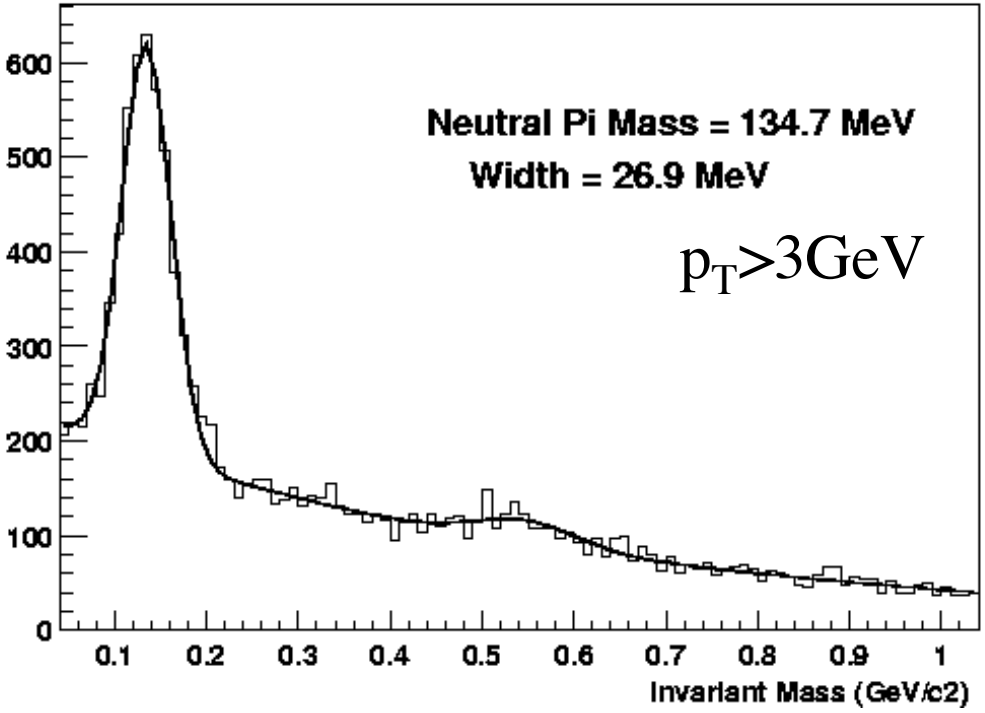
Pre Shower Detector (first 2 layers)

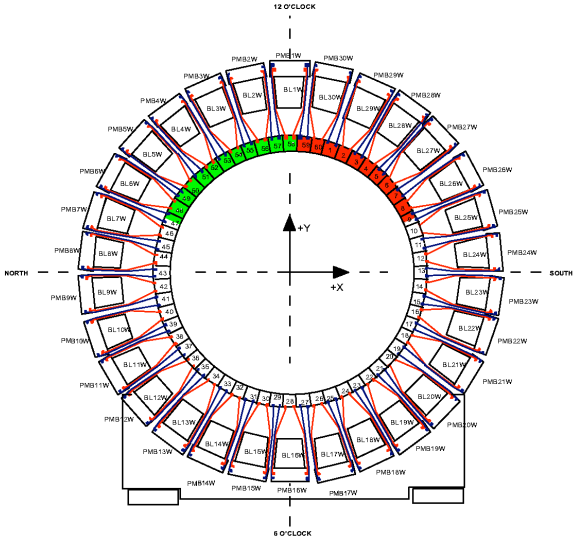
High tower trigger & 1x1 jet trigger



24/120 BEMC modules installed in Spin Year 1

Commissioned, calibrated, high tower trigger is tested





+ Installed in Spin Year 1

60 modules spin year2

90 modules spin year3

All spin year4

Endcap EMC

Scinti. + Pb sandwich EMC

720 projective towers (2□, 1.09<□ <2)

Scinti. Strip Shower Max Detector

Pre Shower Detector (first 2 layers)

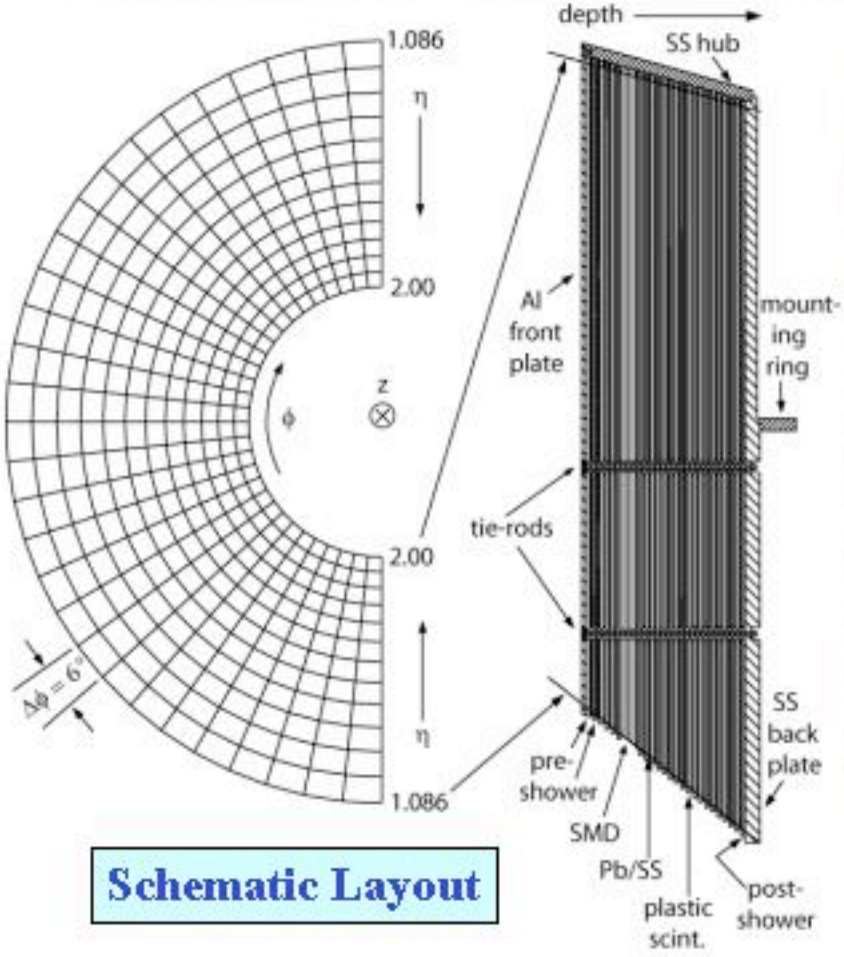
High tower trigger & 1x1 jet trigger

Covers higher rapidity = asymmetric collision

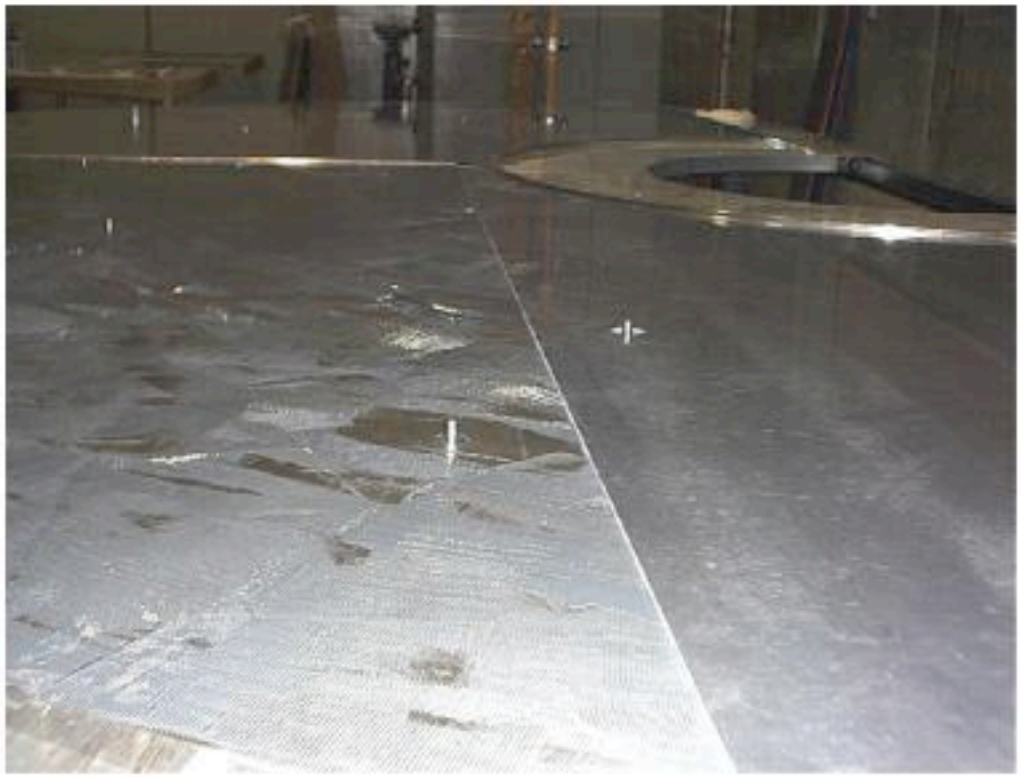
Essential for □G, W measurements

Installation is starting just right now

Few modules for commissioning in Spin Year2



Schematic Layout



Pb/SS Lamination in Progress

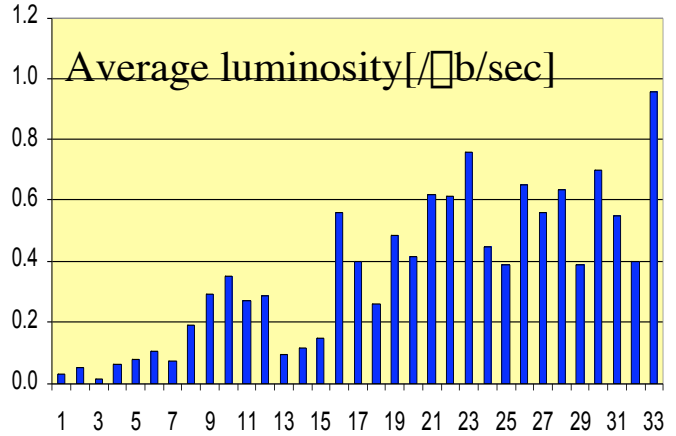
Spin Year 1(FY02) Polarized pp Run 12/20/01 – 1/24/02

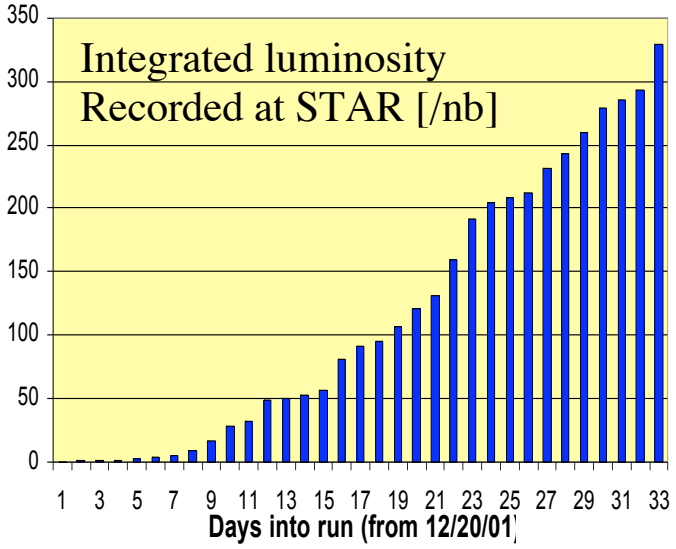
sqrt(s)=200 GeV

Luminosity ~ 10^{30} /cm^2/s

Vertical polarization ~0.2 @ injection energy

STAR BBC measurements





16M Minimum Bias triggers

- Spectra of charged hadrons
- Spin effects at mid rapidity → J.Balewski's Talk
- Au+Au comparison

3.5M FPD triggers with STAR detector

11M FPD triggers standalone data

- A_N for forward pi0 → G. Rakness's Talk

0.8M EMC triggers

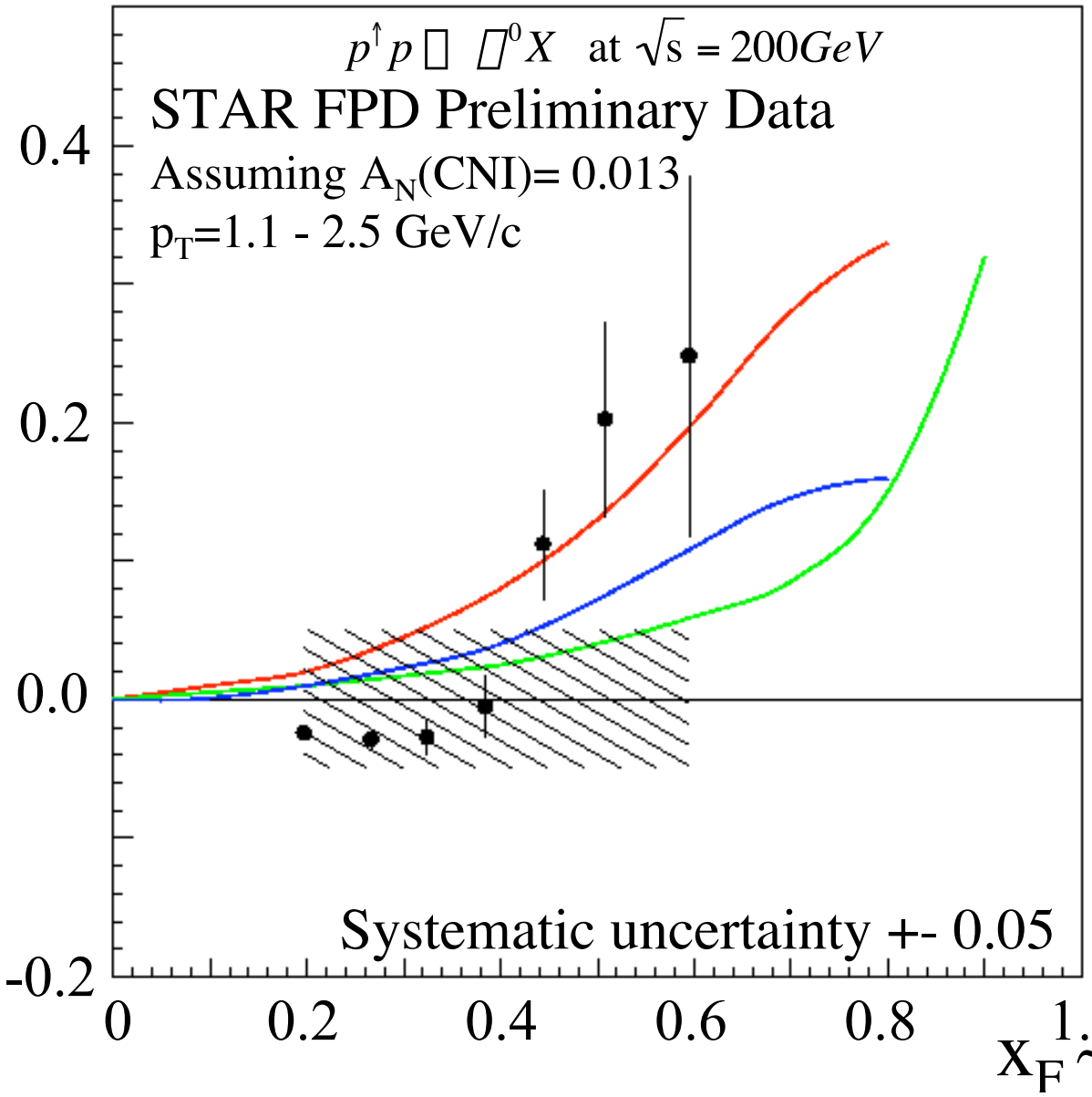
- Commissioning of EMC
- High pt

8000M scaler events with BBC coincidence

- Luminosity measurements
- A_N for forward charged particles → J. Kiryluk's Talk

From G.Rakness's Talk

Forward rapidity high x_F π^0 A_N



Theory predictions
at p_T = 1.5 GeV/c

Collins effect
Anselmino, et al.
PRD 60 (1999) 054027.

Sivers effect
Anselmino, et al.
Phys. Lett. B442 (1998) 470.

Twist 3 effect
Qiu and Sterman,
Phys. Rev. D59 (1998) 014004.

$x_F \sim$ E / 100 GeV

From J.Balewski's Talk

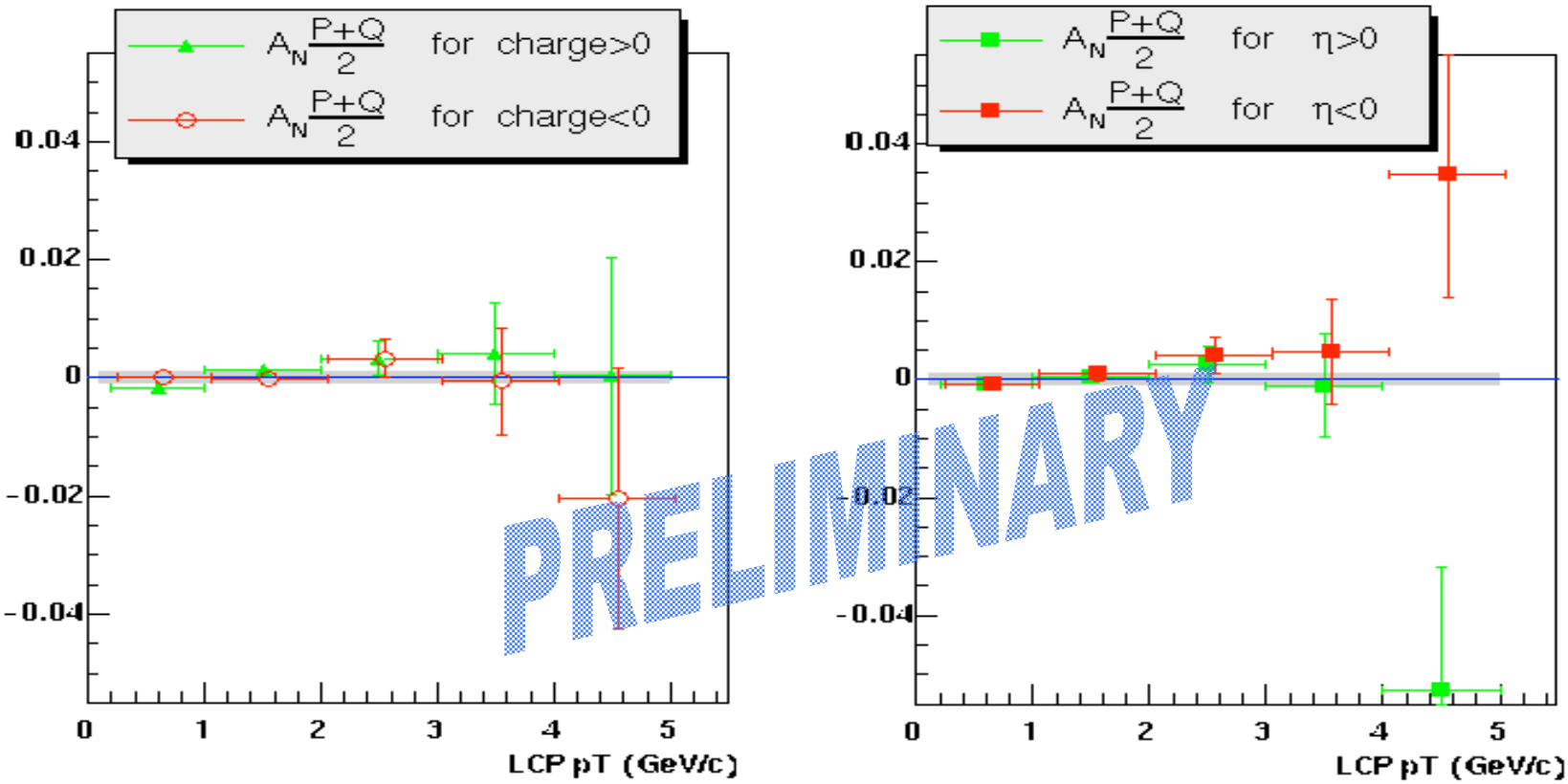
Mid rapidity leading charged particle A_N

A_N*(P+Q)/2 physics 1-spin raw asymmetry

Could be non-zero

Not sensitive to L monitor

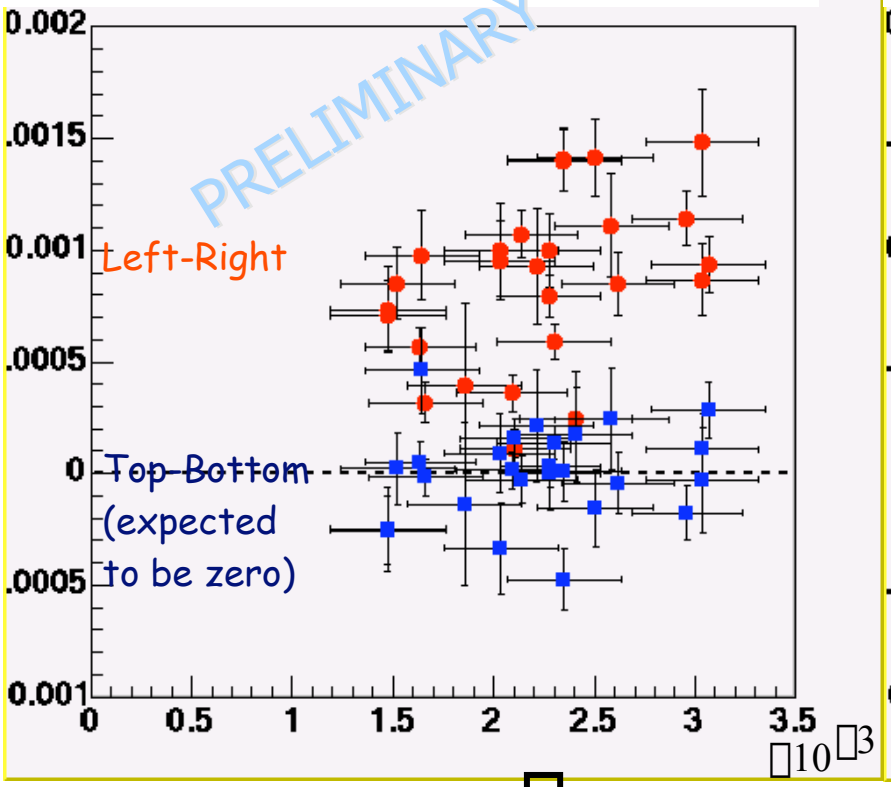
- **Statistical error based on 6.1M events**
- **primary track multiplicity >3**
- **L monitor not used**
- **average polarization P= - 8% , Q= - 14%**



From J.Kiryluk's Talks

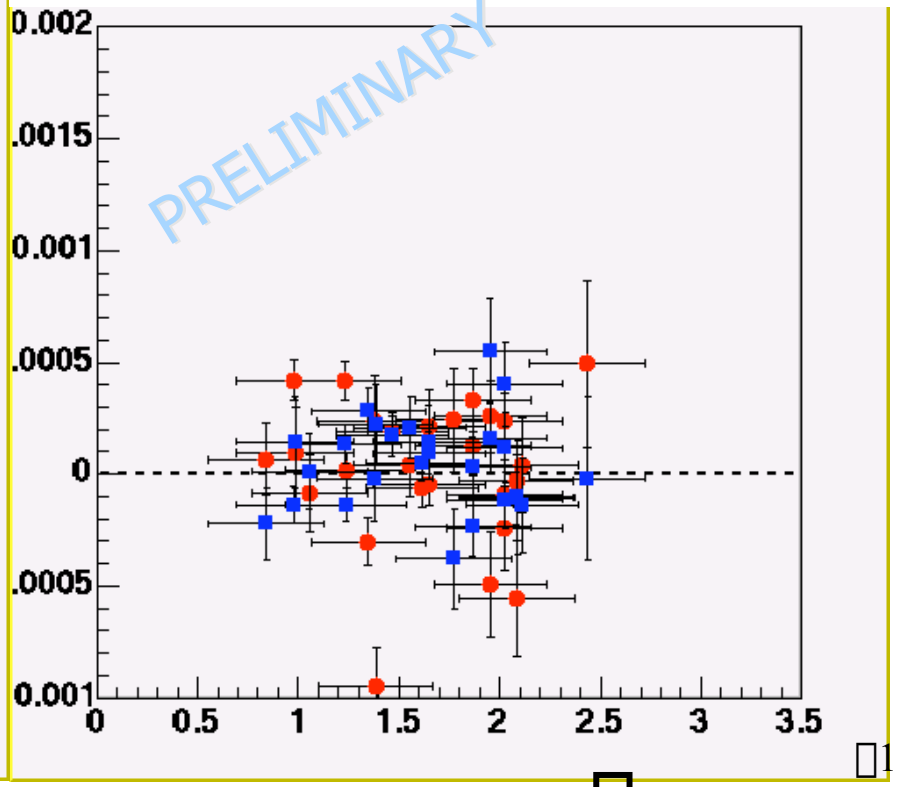
Transverse single spin asymmetry at BBC

(BBC), xF>0



(CNI) (Yellow)

(BBC), xF<0



(CNI) (Blue)

Spin effects are of the order of 10^{-3} , comparable with those observed by CNI

Only statistical uncertainties on the CNI and BBC asymmetries shown.
BBC asymmetries: point to point systematic uncertainty is ~3 x 10^{-4} ,
overall systematics under study

In RHIC collider environment, STAR can measure R with R<10^{-3}

Time Table

Spin Year 1 (2001 Jan)

200GeV Vertical P~0.2 L~10^{30}/cm^2/s
Partial barrel EMC, FPD, BBC
A_N from FPD, TPC, BBC
We've delivered what we promised

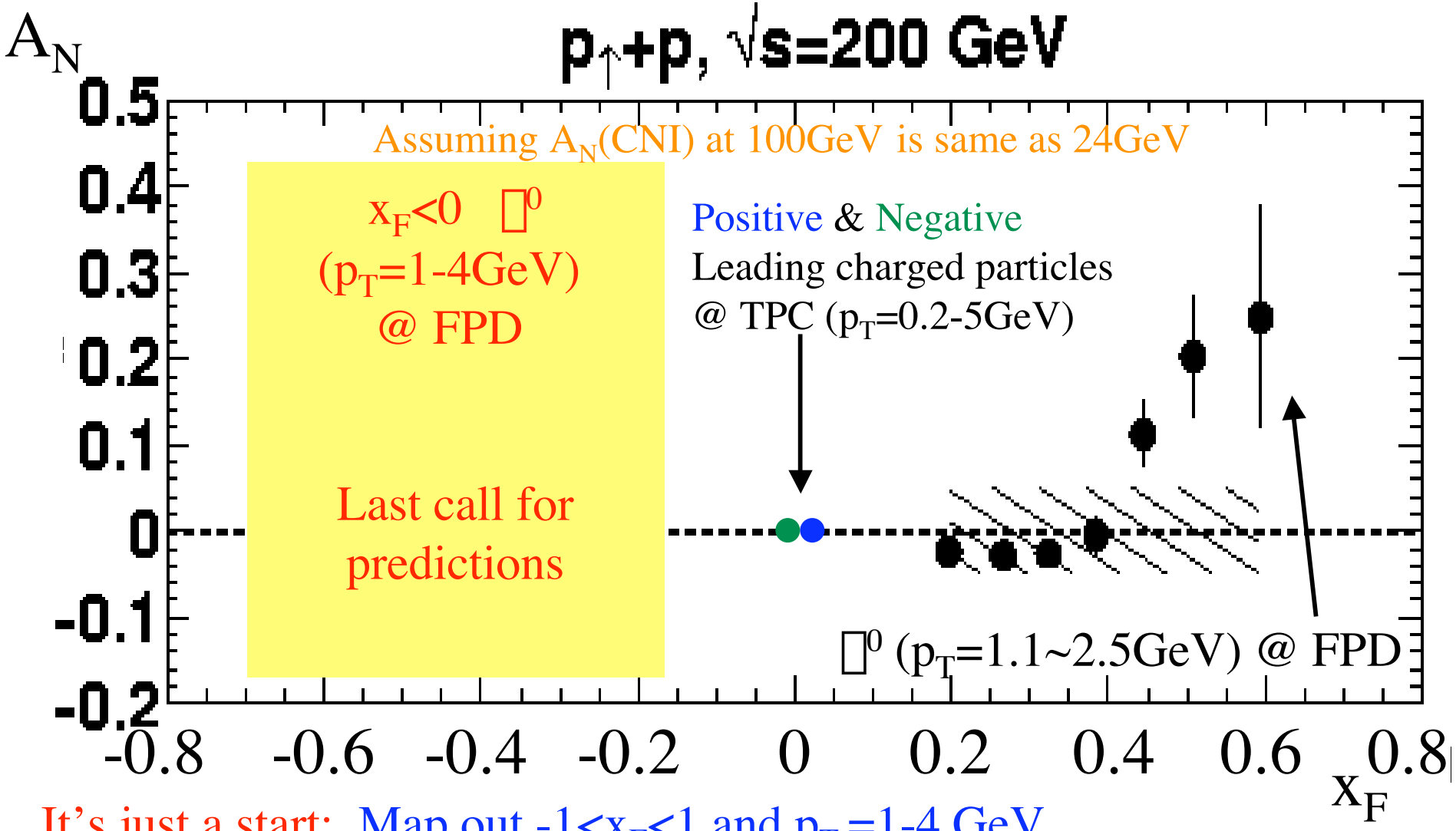
Spin Year 2 (2003 Winter-Spring)

Vertical & Long. P~0.4 L~10^{31}/cm^2/s
200GeV (some 500GeV for test)
Full set of spin rotators
Down-ramp for polarimeter calib.
1/2 barrel EMC, Some endcap EMC
FPD & BBC & Scaler upgrade
5 weeks of setup + machine ramp up
1 week of physics with vertical spin
2 weeks of physics with longitudinal spin
Continue on A_N (F.o.M increases by ~2 orders) → A. Ogawa's Talk
A_{LL} from Jets → B. Surrow's Talk

Spin Year 3 and beyond (2004 ~)

Further improvements on L and P
Eventually up to P=0.7 L= 2*10^{32}/cm^2/s
sqrt(s) = 500GeV
Gas jet polarimeter (Spin Year 3 ~)
Strong snake in AGS (Spin Year 4)
Complete barrel (Spin Year 2 to 4)
Installation of endcap (Spin Year3)
Direct Photons & di-Jets
Ws and Zs
Transversity
New physics?

From A. Ogawa's Talk

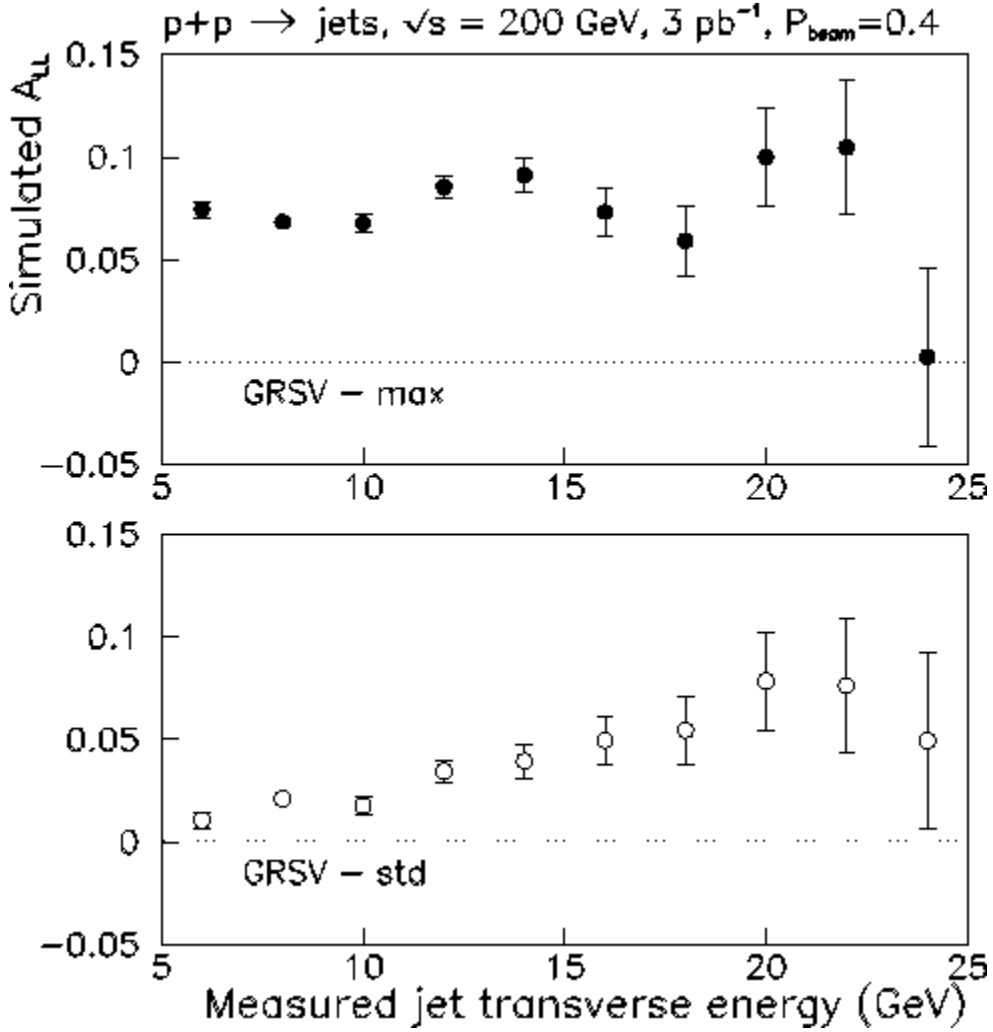


It's just a start: Map out -1<x_F<1 and p_T =1-4 GeV
Sqrt(s)=500GeV, FPD+BBC+FTPC (forward "jet")
FPD-TPC away side correlations (hard process?)

From B. Surrow's Talk

A_{LL} from jet for Spin Year 2

- A_{LL} sensitivity (incl. trigger & detector effects)



- Simulation based on Pythia including trigger and and jet reconstruction efficiencies
- Assume: Coverage of EMC (barrel) $0 < \eta < 2\pi$ and $0 < \eta < 1$
- Jet Trigger: $E_T > 5$ GeV over at least one "patch" $\Delta\eta = 1 \times \Delta\phi = 1$
- Jet reconstruction: Cone algorithm(seed = 1GeV, R = 0.7)
- Luminosity: $3pb^{-1}$
- Polarization: 0.4
- $\sqrt{s}$ = 200GeV

Summary

- Wide range of physics
  - ΔG from direct photon+jet, single and di jets
  - Flavor decomposition of quark & anti-quark polarization
  - Transversity
  - Single spin asymmetries
  - and more…

- First spin physics from RHIC was reported at this conference
  - Commissioned new detectors: BBC, FPD, EMC, Scalers
  - A_N from FPD, TPC and BBC
  - We've delivered what we promised

- Many years of program
  - Higher polarization, more luminosity, better polarimetry
  - Complete STAR detector Barrel and endcap EMC…
  - Understand the system Relative luminosity, polarization